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GEOLOGICAL AND GROUNDWATER INVESTIGATIONS
IN THE MARMOT CREEK EXPERIMENTAL BASIN
OF SOUTHWESTERN ALBERTA, CANADA

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY
by
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UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Geological and Groundwater Investigations in the Marmot Creek Experimental Basin of South-western Alberta, Canada," submitted by Douglas Roy Stevenson, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.



MARMOT CREEK BASIN

ABSTRACT

This report is a preliminary assessment of the geological and groundwater investigations of the Marmot Creek basin undertaken by the Research Council of Alberta. This basin is a watershed management study basin in spruce-fir forest. Soils, vegetation, and surface hydrologic characteristics of the basin are being studied by co-operating government agencies.

Eighteen water-table observation wells and eight piezometers were installed to measure fluctuations of the water table, establish phreatic divides, and define limits of the groundwater reservoir. Wells and piezometers have not been installed in the upper part of the basin because of difficult access. Groundwater records span almost two years for most wells, whereas streamflow and weather data cover up to four years.

Marmot Creek basin is formed in dominantly fine-grained, well-cemented Mesozoic sedimentary rocks of generally low permeability. The bedrock is covered by glacial materials and colluvium as much as 100 feet thick in places with high apparent infiltration characteristics. Because of the lack of subsurface information for the mid-slopes and upper part of the basin, thicknesses of surficial deposits and surface area of the basins contributing to base flow during low-flow recession periods are approximations. The groundwater reservoir appears to be largely unconfined, being recharged directly by precipitation and depleted to supply stream base flow.

A mean groundwater-stage hydrograph was prepared to show mean water-table elevation for the wells with complete records. The hydrograph is judged to cover the average range of fluctuation of the water table although the wells used do not penetrate all the surficial deposits. Mean groundwater stage was plotted against base flow for low streamflow recession periods. This curve is nearly linear for low flow periods. The rating curve and the mean groundwater-stage hydrograph were used to determine the base-flow contribution to streamflow as recorded

at the outlet of the basin. Streamflow seems to be strongly influenced by the sub-basin characteristics.

An annual hydrologic budget was calculated, based on 1965 and 1966 stream records, and an estimated gravity yield, for the interval between times when the vadose zone was saturated and surface-moisture storage was negligible. Approximate precipitation was 35 inches of which 59 per cent formed streamflow, whereas 43 per cent was used by evapotranspiration; the two per cent deficit was made up from groundwater storage.

A groundwater budget was calculated for the same time interval based on the mean groundwater hydrograph and calculated gravity yield. Thirty four per cent of the streamflow was base flow, and 61 per cent of the total evapotranspiration loss was from groundwater; the remaining 39 per cent of evapotranspiration was supplied from the vadose zone. Potential evapotranspiration calculated by the modified Penman method was about 12 per cent higher than the open water evaporation (determined from corrected Class A pan data for June, July, and August, 1965) and was as large as previous annual estimates for this area.

Stream waters and groundwaters within the basin are of the calcium and magnesium bicarbonate type. Concentration of dissolved solids in stream waters is proportional to the base-flow contribution to stream discharge.

Additional investigation is required to determine the effects of soil freezing on water-table fluctuations, the amount of underflow at sub-basin stream discharge stations, to measure fracture permeability in shale members, to measure the gravity yield of surficial materials, to evaluate networks of small-diameter piezometers and to assess chemical changes in groundwater.

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INTRODUCTION

General Statement

Watershed research began in the Saskatchewan River headwaters in 1960 with the ultimate objective of establishing working relationships between land management and improved water yield. This research program includes the establishment of small, experimental drainage basins in different parts of the headwaters and the correlation of the physical characteristics of each basin with basin hydrology. Establishment of the physical characteristics of the basin consists of mapping basin topography, soil types, and surficial and bedrock deposits. Study of basin hydrology consists of instrumentation and measurement of water moving into and out of the basin and of change in water storage within the basin, both above and below the land surface. The Research Council of Alberta, one of a number of provincial and federal agencies involved, undertook the geological mapping and groundwater research within the experimental basins.

The Marmot Creek Basin

The Marmot Creek basin is located at latitude 50°57'N and longitude 115°10'W on the east flank of Mount Allan in the Kananaskis River valley. The basin may be reached by travelling 50 miles west of Calgary on the Trans-Canada Highway to the Kananaskis Forestry Trunk Road and from there approximately 10 miles south to the Ribbon Creek campground (Fig. 1).

The Marmot Creek basin was selected in 1962 as a site in which to study the hydrology of spruce-fir forest which is the primary source of lumber within the Saskatchewan River headwaters. Timber harvesting is currently being carried on in the commercial subalpine zone (below 6,500 feet)*. Consequently, erosion and sedimentation and uncontrolled changes in water yield are most active within this zone (Jeffrey, 1961).

*All elevations referred to in this report are above mean sea level.

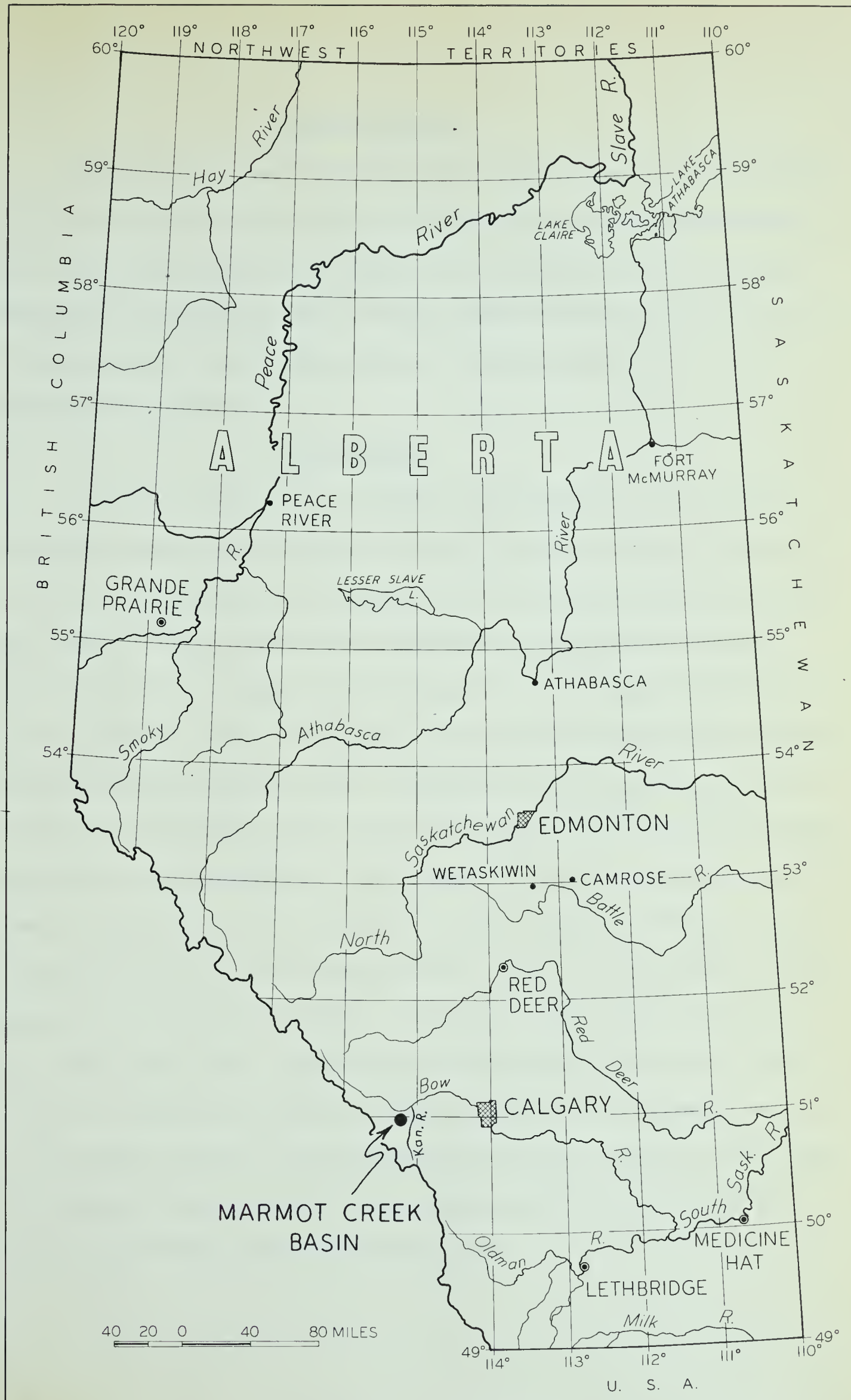


Figure 1. Index Map

Program Objectives

The basic objectives of the Marmot Creek basin program are: (1) to establish interrelationships between physical characteristics and hydrology of drainage areas within undisturbed spruce-fir forest; (2) to measure the effects of current timber-harvesting practices upon basin yield, regime, and water quality; and (3) to test and develop better cutting patterns and logging practices for improved watershed management.

Previous Work

In 1947 and 1948 M.B.B. Crockford of the Research Council of Alberta mapped the geology of the Ribbon Creek area, including the Marmot Creek basin, as part of a detailed survey of coal deposits within the Cascade Coal Basin (Crockford, 1949). In 1961 a reconnaissance geological and groundwater survey of Marmot Creek basin was carried out by R. Green and J.F. Jones of the Research Council of Alberta, as part of the basin selection procedures followed in selecting experimental basins (Jeffrey, 1964). The results of this survey (Green and Jones, 1961) were instrumental in the acceptance of the Marmot Creek basin for the study of spruce-fir forest hydrology. In 1963 a geophysical survey was carried out in the Marmot Creek basin by V.A. Carlson of the Research Council of Alberta, using a Hunting FS2 hammer seismic instrument (Carlson, 1963). The thickness of surficial deposits was calculated for 32 stations. The seismic results compared most favorably with borehole results wherever the surficial materials were less than 30 feet thick. Mr. Carlson concluded that stronger signal-generating equipment was necessary because of the high level of background noise due to wind and running water and because of strong attenuation of the seismic signal by deep mosses and other organic material found in the Marmot Creek basin.

Present Work

The writer spent approximately five months in the Marmot Creek Basin area during the field seasons of 1964 to 1966. The Mount Allan sections of Mesozoic strata measured and described by Crockford were examined, as well as the bedrock outcrops exposed along Ribbon Creek and the creeks in the Marmot Creek basin. Ground-water discharge features were mapped and a network of eight piezometers and 18 water-table observation wells was installed. Aerial photographs in scales of 1:7,920 and 1:40,000 and the geological maps from the Ninth, Eleventh, and Thirteenth Annual Field Conference Guide Books of the Alberta Society of Petroleum Geologists (1959, 1961, 1963) were used in studying the areal geology.

Aerial photographs were useful in locating structures and stratigraphic contacts within the Paleozoic and Lower Cretaceous strata, as well as contacts of scattered Pleistocene glacial and glaciofluvial deposits, and postglacial alluvial deposits. Contacts of Kootenay, Fernie, and Spray River Formations were mapped from field observations along the creeks and by structural geology techniques.

A study of the geology of the surrounding area was necessary to understand the geology of the Marmot Creek basin.

GEOGRAPHIC AND GEOLOGIC SETTING OF THE GENERAL AREA

Topography

The general area lies within the first range of the Rocky Mountains and extends from the Bow River to just south of the confluence of the Evans-Thomas Creek and the Kananaskis River (Map 1).

The natural topographic divisions in the area are the river valleys and the flanking alpine mountain ridges. The mountain ridges have been formed from a succession of subparallel, west-dipping thrust blocks. These ridges generally trend north-northwest and have elevations of 8,000 to 10,000 feet. The minor valleys in the area generally parallel the mountain ridges and have been formed in the more easily eroded units of folded or faulted strata. These valleys are drained by subsequent streams into the major valleys.

The two major river valleys in the area are drained by the Bow and Kananaskis Rivers. The Bow and Kananaskis Rivers trend eastward and northeastward, respectively, across the first range of the Rocky Mountains from either side of the structural saddle of Mount Allan and reach a confluence in the upper foothills.

Climate and Hydrology

The climate of the area, based on the Köppen classification, is humid continental with cool summers (Canada Department of Mines and Technical Surveys, 1957). During the summer, Pacific air moving east over the mountains mixes with overlying, dry inland air assuming properties of continental air (dry) on crossing the Continental Divide (Heusser, 1956). During the winter polar marine air from the northwest is cooled to near continental conditions as it crosses the mountains and passes over the general area. Occasional polar continental or mild Pacific air masses moving over the area result in winter temperature extremes. The mixed air conditions generally result in a fairly even areal distribution of precipitation, the major part occurring as snowfall. Table 1 lists climatic parameters measured,

climatic data, and the number of years of record from adjacent weather stations.

Figures 2 and 3, showing average annual precipitation and average annual runoff, indicate that precipitation and water yield are high within the mountains, falling off rapidly as the foothills and plains are approached. Evapotranspiration is low within the back ranges of the mountains and much greater in the foothills, with no significant variation from southeast to northwest (Laycock, 1957). Major stream discharges occur during June and July, resulting from a combination of early summer rains and snowmelt. Late summer peaks also result from rainfall and snowmelt, while winter flow is supplied from the gradual depletion of groundwater storage.

Vegetation

Moss (1955) has generally divided the area into supalpine and alpine regions.

Subalpine region

Vegetation in the subalpine region is dominantly coniferous and extends from the valley bottoms to the forest line approximately 7,500 feet above sea level in the Kananaskis area. The most important forests in this region are white spruce (Picea glauca) and lodgepole pine (Pinus contorta), with alpine fir (Abies lasiocarpa) and Engelmann spruce (Picea engelmanni) found at higher elevations. In the high subalpine zones alpine larch (Larix lyallii) and whitebark pine (Pinus albicaulis) are found.

The lodgepole pine forests have an age-class distribution (Bloomberg, 1950) attributed to fire, and usually appear as dense even stands in areas that have been burned over. Lodgepole pine associations, "under either open or dry conditions or both," include bearberry (Arctostaphylos uva-ursi), juniper (Juniper spp.) and hedsarum (Hedysarum), while under temporary moisture conditions frequently associated shrubs, herbs, and feather mosses are Cornus canadensis, Ledum groenlandicum, and Equisetum spp. (Moss, 1955).

Spruce-fir stands remain in remote valleys and in the more rugged areas that

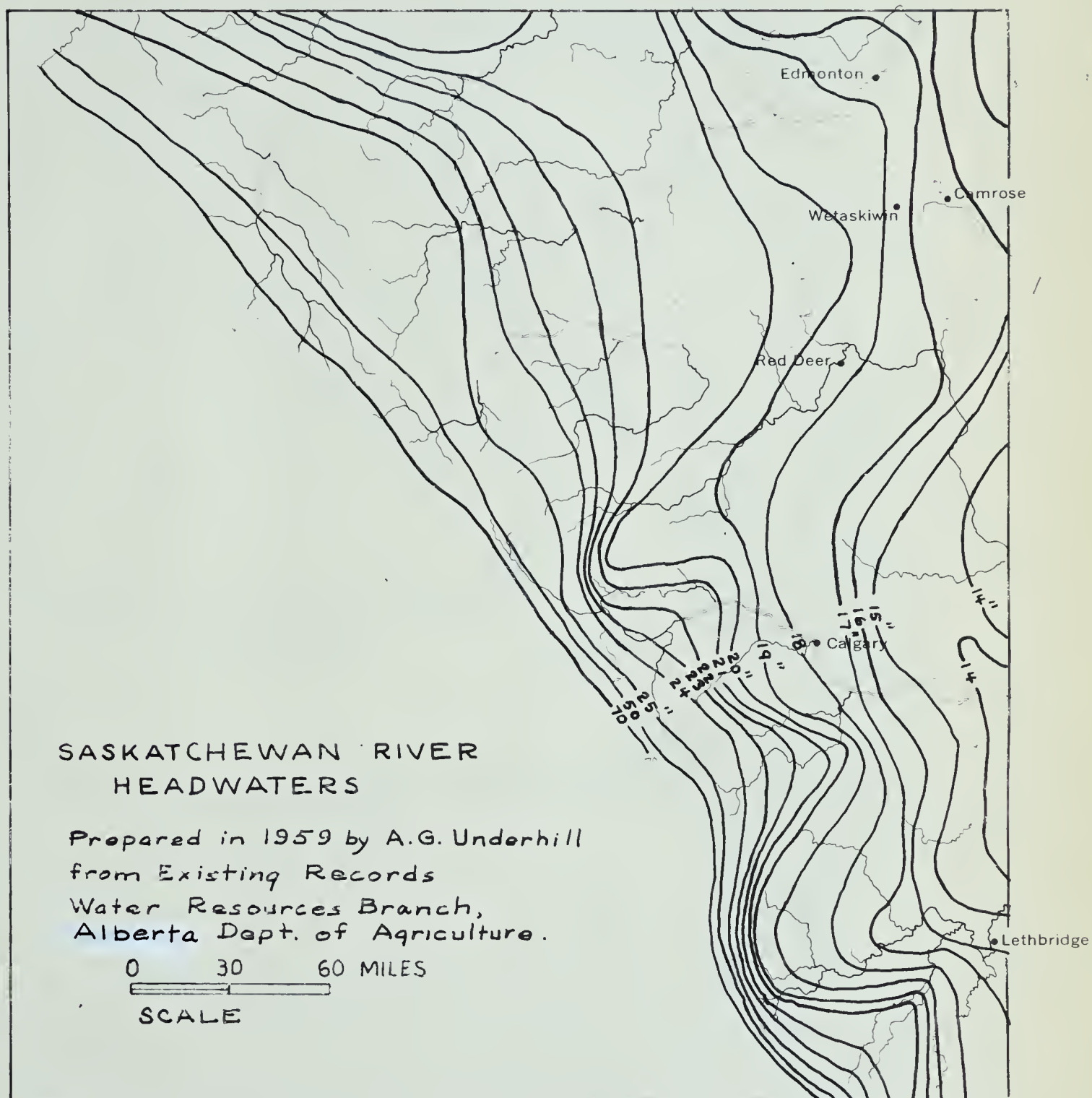


Figure 2. Average Annual Precipitation in Inches

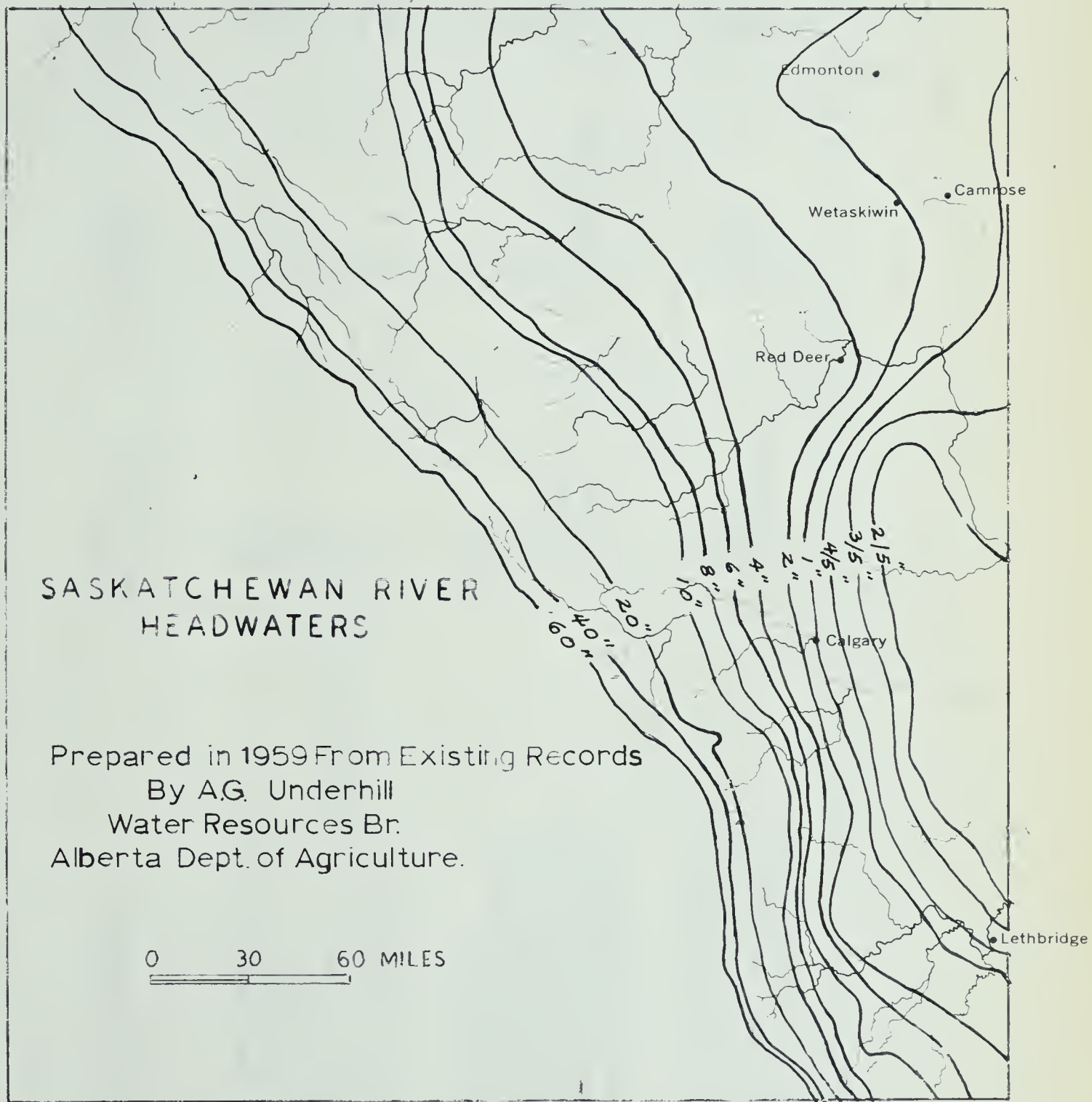


Figure 3 Average Annual Runoff in Inches.

Table 1. Meteorological Data from Weather Stations in the Kananaskis Area

Climatic Parameters	Banff (elev. 4,583')	Exshaw (elev. 4,260')	Kananaskis (elev. 4,560')
Precipitation			
Mean total yearly (in inches)	18.7	20.5	25.2
Rain (in inches)	10.9	12.5	14.9
Snow (in inches)	7.8	7.8	10.0
Days with at least 0.01 inches precipitation	123	91	97
Days with at least 0.1 inches snow	58	37	49
Number of years observed	29	15	21
Temperature			
Yearly mean (°F)	36	39	37
Yearly daily maximum (°F)	47	49	49
Yearly daily minimum (°F)	25	29	25
Maximum month (mean) (°F)	58, July	61, July	58, July
Minimum month (mean) (°F)	13, Jan.	19, Jan., Feb.	15, Jan.
Number of years observed	29	15	21
Wind			
Yearly mean speed (mph)	6	--	6
Maximum per cent frequency	38 SW	55 SW	31 SW
Minimum per cent frequency	3N, SE, S	0 S	4 SE
Number of years observed	24	8	11

have remained free from fire. Spruce-fir associations are characterized by a variety of small trees, shrubs, herbs, and fern grasses scattered under the canopy. These include Salix spp., Alnus spp., Vaccinium scoparium, Equisetum spp., and Carex spp.

In wet, poorly drained areas a black spruce (Picea mariana) - feather moss (Hylocomium splendens) association frequently exists, often including white spruce, aspen (Populus), willows (Salix), lichens, and sedges (Carex).

Alpine Region

Alpine vegetation is found between the timber line of the subalpine forest and the snow line.

Lewis (1923) divided the alpine vegetation region into three zones: the transition zone, the scrub zone, and the zone between the scrub line and the snow line.

The transition zone, between forest line and tree line, is characterized by small groves of trees and isolated individuals. The chief tree species are alpine fir, Engelmann spruce, alpine larch, and whitebark pine. Surrounding the tree groves are varieties of alpine meadow grasses, herbs, and heaths.

More stunted varieties of the same tree species are scattered within the grass and herb meadows of the scrub zone or "Krummholz." Shrubs, characteristic of different moisture conditions within the scrub zone, are dry shrub (Dryas), found in dry sites, mesic shrub (Phyllodoce), found in temporarily wet sites, and the seepage variety of shrub (Salix) found in permanently wet areas (R.T. Ogilvie, personal written communication).

Above the scrub line the vegetation consists mainly of mosses, herbs, and lichens. Due to the heterogeneity of the rock and soil conditions, a diversity of local plant communities exists. These are mostly perennial and contain many arctic species (Daubenmire, 1943).

Soils

Few detailed soil studies have been carried out in the area. D.I. Crossley (1951) of the Forest Research Branch, Canada Department of Resources and Development, prepared and published a report on subalpine soils in the Kananaskis Forest Experimental Station which is located 10 miles north of the Marmot Creek basin. The soil types found in the general area are similar to the soils of the Marmot Creek basin described in this report.

Bedrock Geology

Stratigraphy and Structure

The general area lies within the first range of the Front Range (North and Henderson, 1954) bounded to the east by the McConnell thrust block and to the west by the Mount Rundle thrust block (Map 1). The first range is further subdivided in this area by the Exshaw and Lac Des Arcs thrust blocks. These thrust blocks generally strike north-northwest and dip from 30 to 45 degrees west. The McConnell thrust block exposes approximately 6,000 feet of dolomites, calcareous shales, and limestones of Middle Cambrian, Devonian, Mississippian, and Permian ages. The Exshaw thrust block - made up of limestones, shales, and dolomites of Mississippian and Devonian ages - overlies the McConnell thrust block. The Lac Des Arcs thrust block overlies the Exshaw thrust block and exposes most of the Paleozoic sequence of the McConnell block plus approximately 5,000 feet of Mesozoic rock units. Folds of Paleozoic limestones and dolomites of the Lac Des Arcs Block can be observed in the Bow River gap area north of Pigeon Mountain. These folds tighten to the southeast and are replaced by thrust faults on Mount Lorette. Farther southeast comparable folds are exposed on the east wall of the Evans-Thomas Creek valley; these folds plunge northward as they approach the Kananaskis River.

The Mesozoic rock units of the Lac Des Arcs block consist of siltstones, black shales, argillaceous sandstones, coals and silty shales, cross-bedded sandstones,

and conglomerates ranging in age from Early Triassic to Early Cretaceous. These Mesozoic strata are regionally folded into a large overturned syncline. This structure, called the Mount Allan Syncline, is locally cored with basal Blairmore conglomerates preserved as topographic highs within the synclinal trough; the highest of these rises to an elevation of 9,150 feet to form Mount Allan.

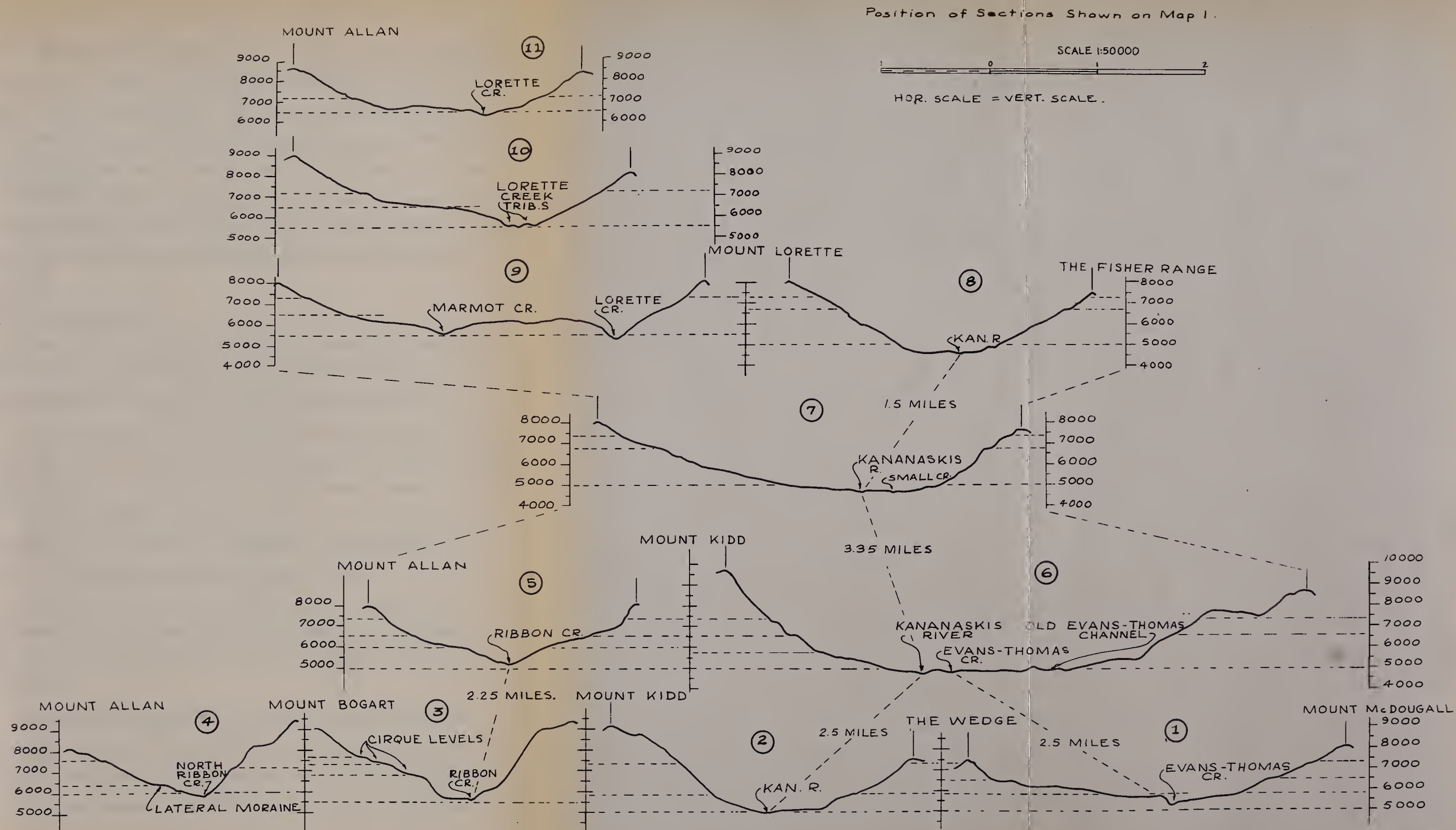
The Mount Allan Syncline plunges approximately 150 feet per mile to the northwest to form the Cascade Coal Basin (Crockford, 1949), while increasing in elevation to the southeast where Mississippian rocks of the Mount Rundle thrust block are faulted against Mississippian rocks of the Lac Des Arcs thrust block just to the south of the general area.

Surficial Geology

Pleistocene and post glacial deposits are found throughout the river valleys and along most of the creeks in the area, whereas the mountain ridges show many classic examples of alpine glaciation.

Glacial Erosional Features

The most notable glacial erosional features in the alpine zone are the extensive cirque development with the associated cols, aretes, and horns. Usually there are two or three steps in each cirque floor, ranging in elevation from 6,600 feet to 7,600 feet in the map area. The highest cirque noted in the area is carved out of the south face of the Fortress at the head of Smith-Dorrien Creek. This cirque floor is the highest of three steps and stands at an elevation of 8,100 feet. The lowest cirque noted in the area appears as a hanging valley on the east face of the Kananaskis Range at an elevation of 6,400 feet. Most of the valleys in this area are broad and U-shaped (Fig. 4). Along the upper valley walls faceted spurs are found such as those along the north wall of the Ribbon Creek valley and on the southeast ridge of Mount Allan (L.A. Bayrock, oral communication). Side-glacial stream channels, such as those on the east-facing scarp face of the bedrock bench between



Lorette and Marmot Creeks, mark the former side-valley positions of periodic glacier equilibrium (Rutter, 1965). These side-valley erosional features commonly cause a break in the slope of the valley walls. The most consistent breaks in slope, as shown by cross sections in Figure 4, approximate the 6,400-, 6,700-, and 7,300-foot elevations. Some of these breaks in slope may be depositional in nature such as those observed along North Ribbon Creek (Section 4, Fig. 4), where well preserved lateral moraines are located at an elevation of approximately 6,300 feet. These moraines have been notched by a tributary stream of Ribbon Creek that drains the south slope of Mount Allan.

Glacial Depositional Features

Large lateral reaches of the valley slopes are covered with a veneer of till. These side-valley till deposits appear on aerial photographs as dark forested areas resulting from thicker soil development and better moisture retention properties.

On the east slopes of Mount Allan, elongate ridges cross the Marmot Creek basin (Frontispiece). Associated with these local ridges are large, commonly striated, Paleozoic limestone and quartzite erratics. Since no Paleozoic bedrock is included in the rock units of Mount Allan, it is logical to assume that these erratics were transported by part of the Kananaskis Valley glacier. Limestone erratics have been found in the Marmot Creek area at elevations up to 7,000 feet.

In the alpine zone local cirque moraines are found. These moraines may extend laterally to the end of the cirque where they join to form an end moraine. Hummocky disintegration features are common within the cirques as noted on Mount Allan (Plate I).

Lower in the valleys glaciofluvial ice-contact or outwash features exist. Excellent examples of pitted kame terraces (Plate I) are found at the outlets of the Evans-Thomas and Ribbon Creeks (A. J. Broscoe, 1966, oral communication). These terraces stand approximately 300 feet higher than the adjacent river floodplain. A

braided ridge of granular material extends from the Ribbon Creek valley across the lower east slopes of Mount Allan; a gravel pit located in this ridge exposes stratified materials ranging in size from very fine sand to boulders (Plate I). These extreme variations in texture are characteristic of ice-contact deposits.

Postglacial Deposits

The most spectacular postglacial deposits in the area are the very large alluvial fans aggrading the tributary hanging valleys down to the floodplain of the present Kananaskis River valley (Map 1). The large fans, such as the Ribbon Creek fan, the Lorette Creek fan, and the Evans-Thomas Creek fan have forced the Kananaskis River floodplain toward the opposite valley wall. Large alluvial fans, formed below hanging tributary valleys, have locally plugged the valley below causing river aggradation upstream or floodplain lakes or both to develop. This development has been responsible for the formation of Lac Des Arcs (Rutter, 1965) and thick floodplain deposits just west of Pigeon Mountain in the Bow Valley. Likewise, in the Kananaskis Valley, the Rocky Creek fan has plugged the valley causing the Kananaskis River to aggrade the valley floor upstream.

Active talus is collecting at the base of many of the steep rock cliffs forming the valley walls where the Kananaskis River has cut through the Paleozoic strata of the Lac Des Arcs and the Exshaw fault blocks.

In the alpine zones patterned-ground features are found. Among the most notable are "stone stripes," such as those developed in the cirque on Mount Allan (Plate I).

GEOGRAPHIC AND GEOLOGIC SETTING OF THE MARMOT CREEK BASIN

Topography and Drainage

The Marmot Creek basin lies on the east flank of Mount Allan. The basin outlet is located at the top of a gorge at an elevation of 5,200 feet (Plate II), while the extreme upper limit of the basin is the peak of Mount Allan at an elevation of 9,150 feet. The basin is divided into three sub-basins drained by tributary streams which merge into the lower part of the basin called "the confluence area" (Fig. 5). Topographic characteristics of the Marmot Creek basin and its sub-basins are shown in Table 2, and Figures 6 and 7.

The branches of Twin Creek rise above tree line in steep bedrock and scree-covered slopes where moderate gullying has developed. Down-valley, these gullies are incised and V-shaped, locally exposing the underlying bedrock. Below 6,200 feet, the slope is gentler than above this elevation reflecting a change in rock type. Middle Fork Creek begins in the headwall and steep talus slopes of a well developed cirque. This stream flows over the moderately sloping cirque floor (10 per cent) and leaves the cirque at an elevation of 7,200 feet. Downward the slope of the stream bed changes to approximately 30 per cent as the stream cuts a V-shaped channel into the underlying, morainal ridges. Below 6,200 feet the slope of the stream bed is about 20 per cent. Cabin Creek begins as small gullies cut into the steep scarp face of the upper rock unit. The upper parts of the tributary channels have a 65 per cent slope. Downstream these channels are deeply incised, cutting through thick morainal ridges into the underlying bedrock.

Twin Creek and Middle Fork Creek coalesce just below the 5,800-foot level, and Cabin Creek joins Marmot Creek at the 5,600 -foot elevation.

Marmot Creek continues down-valley in a deep channel to the basin outlet where it drops through a steep gorge some 200 feet to coalesce with an unnamed stream and then drops another 200 feet to a large alluvial fan on the Kananaskis River flood-plain.

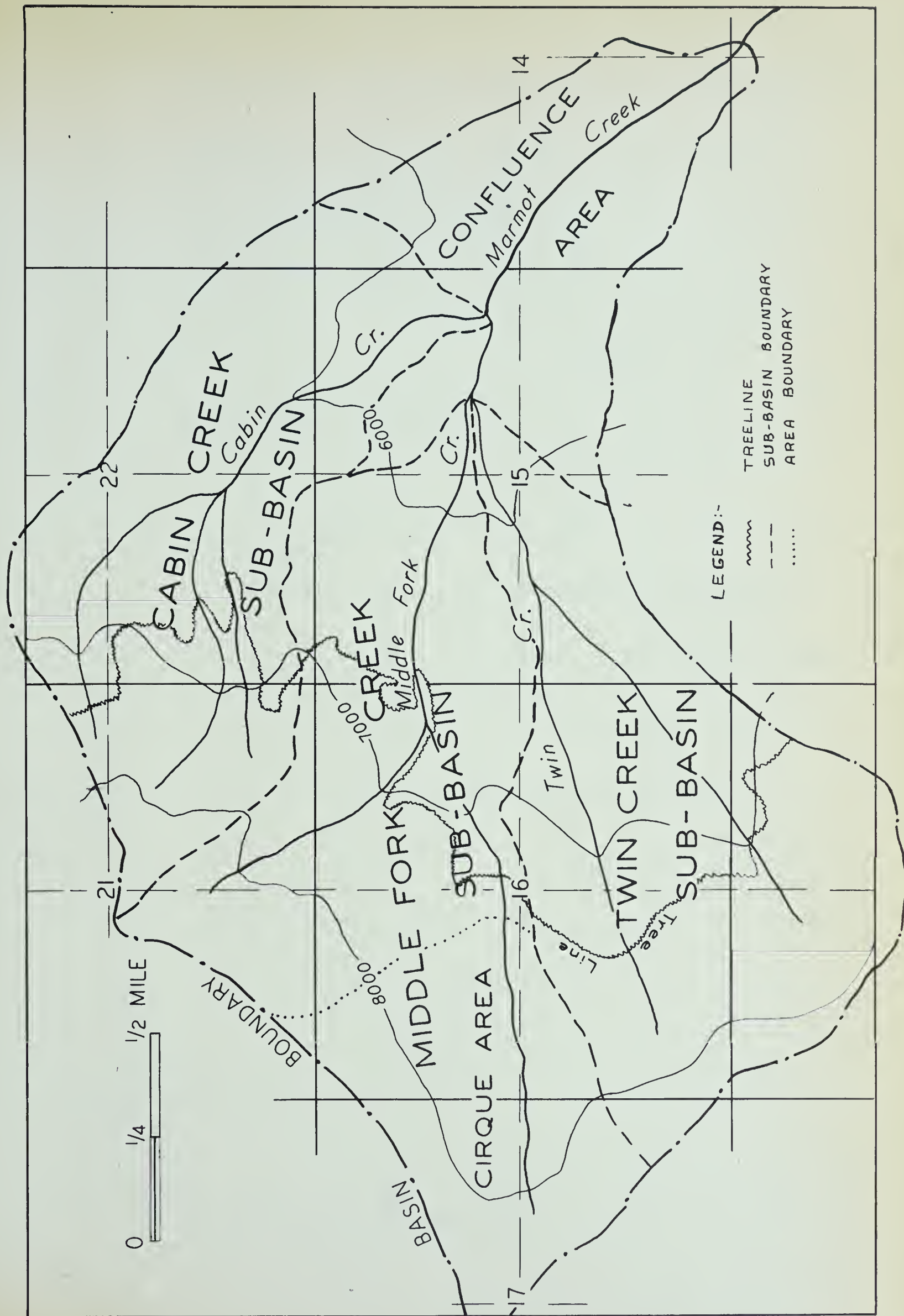


Figure 5. Topographic Subdivisions of the Marmot Creek Basin

MARMOT CREEK BASIN, AREA-ELEVATION CURVES

After G.E. CURRY, Eastern Rockies Forest Cons. Bd.

Legend:

- Marmot Creek Basin
- Cabin Creek
- - - Middle Fork Creek
- . - Twin Creek
- The Cirque

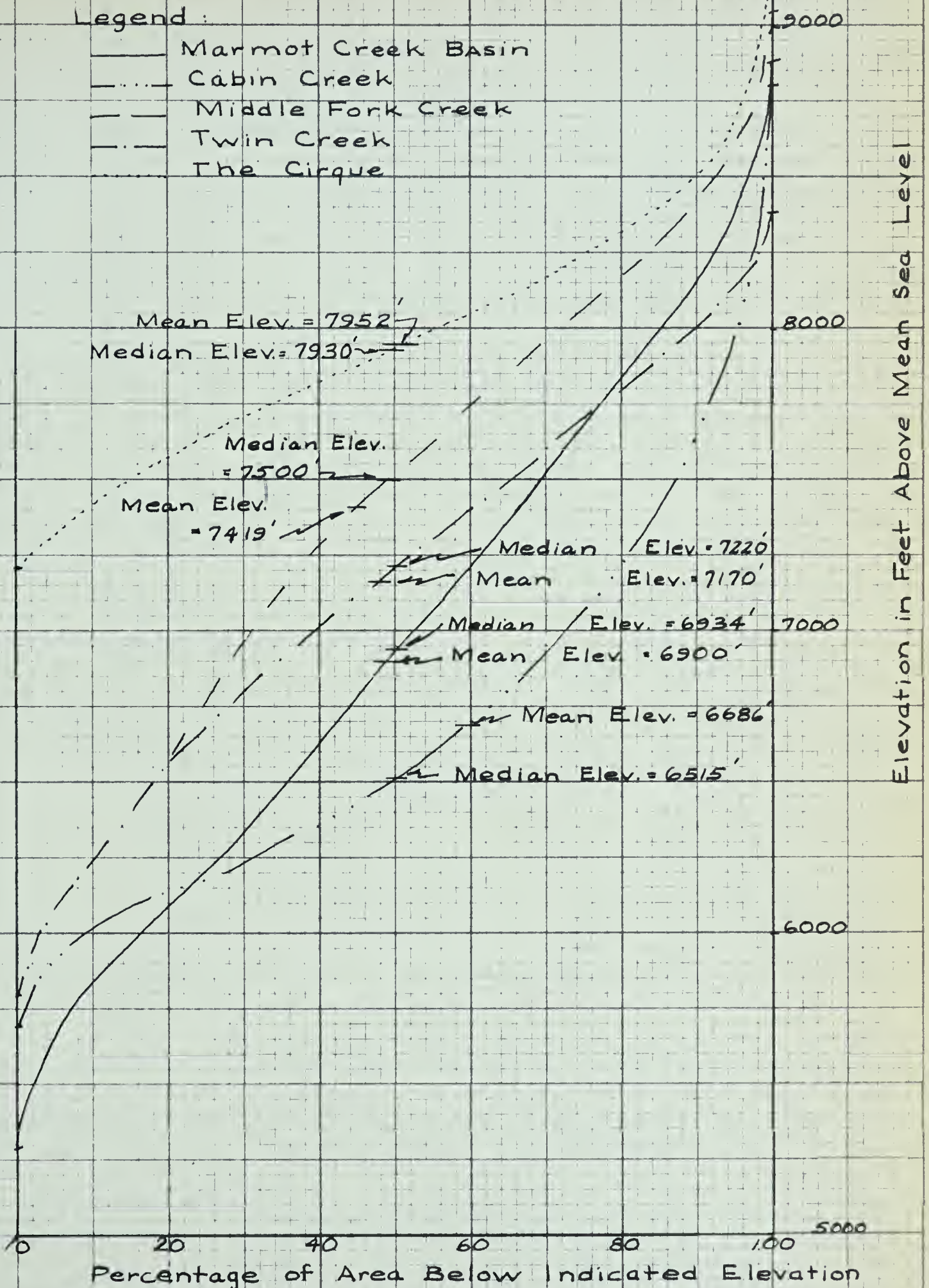


Figure 6. Area-Elevation Curves

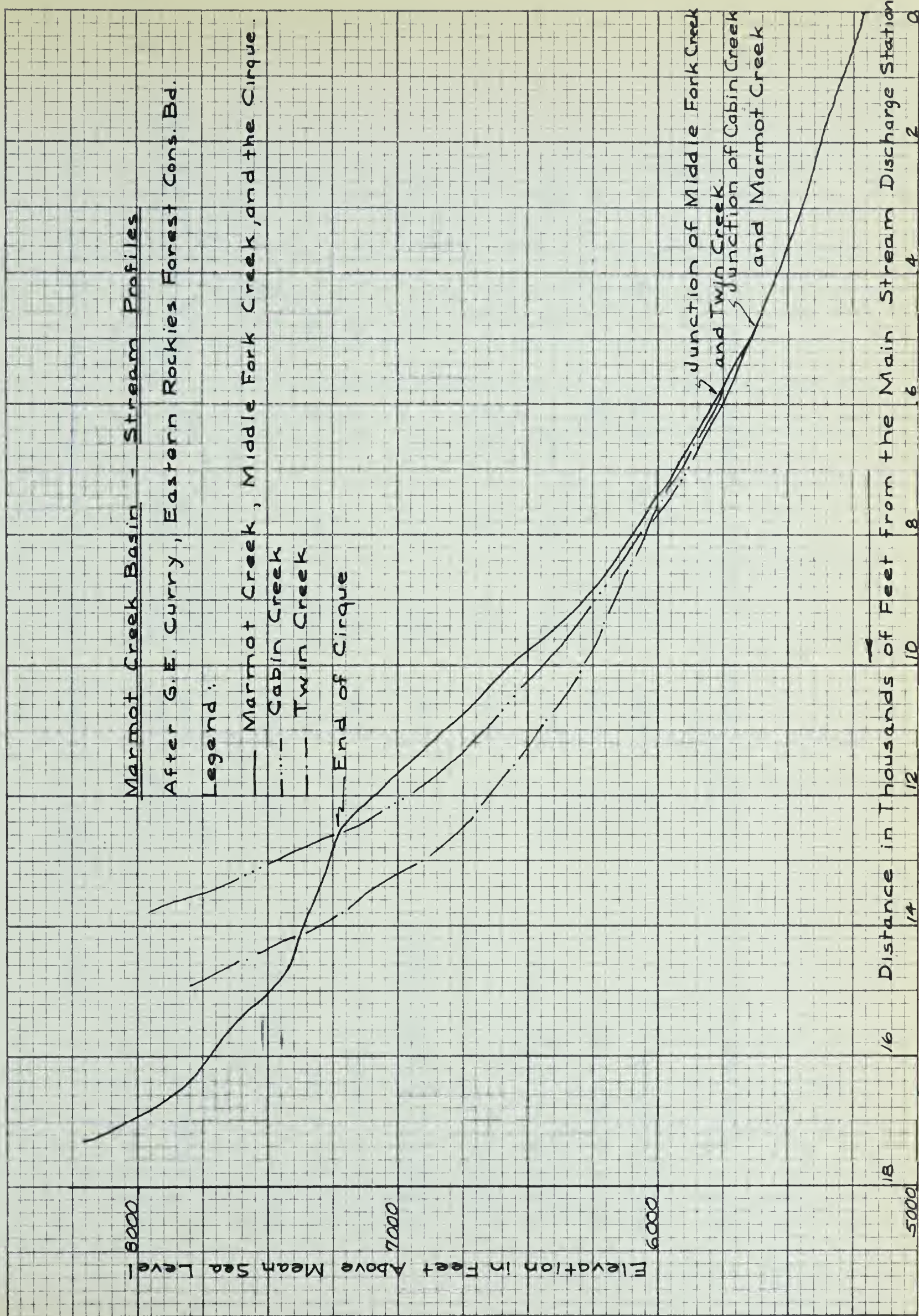


Figure 7. Marmot Creek Basin Stream Profiles

Table 2. Topographic Characteristics and Forest Cover of Marmot Creek Basin and Sub-basins

Topographic Characteristics	Marmot Creek Basin	Cabin Creek Sub-Basin	Twin Creek Sub-Basin	Middle Fork Sub-Basin	Cirque Area	Confluence Area	Middle Fork Sub-Basin Below Cirque Area
Total area in square miles (M)	3.63	0.80	1.00	1.10	0.50	0.73	0.60
Percentage of area	100	22.1	27.5	30.3	13.8	20.1	16.5
Percentage area below 6,500 feet	40.2	45.0	20.0	15.2	0	100	25.5
Percentage area of basin above the alpine zone (6,500 feet MSL)	59.8	55.0	80.0	84.8	100	0	72.1
Percentage of total area above the alpine zone	59.8	12.2	22.0	25.7	13.8	0	11.9
Percentage area of basin above tree line	39.7	24.0	43.4	74.8	100	0	53.8
Stream lengths in miles (l)	11.91	4.03	3.33	3.41	1.05	1.14	2.36
Drainage density $Dd = \frac{l}{M}$	3.28	5.04	3.33	3.10	2.10	1.56	3.63

NOTE: Stream lengths measured from a topographic map having a scale of 1 inch equals 500 feet.

Vegetation

Forest Cover

The distribution of forest cover types in the Marmot Creek basin is shown on Map 2. Forest covers approximately 60 per cent of the basin area from the basin outlet to the tree line (C. Kirby, Alberta Forest Service, 1967, written communication). The remaining 40 per cent of the area lies above the tree line and consists of alpine meadow (80 per cent) and rock and Krummholz (20 per cent).

A stand of fire-generated young lodgepole pine covers the lower slopes of the confluence area. This stand averages 16 years in age and comprises approximately 12 per cent of the tree cover. A small amount of more mature lodgepole pine is mixed with the spruce-fir forests at higher elevations.

Mature stands of spruce and fir range in elevation from 5,500 feet to 7,000 feet above mean sea level and comprise approximately 70 per cent of the tree cover. Alpine fir and larch are found between 7,000 feet and the tree line. Combinations of mixed forest types are found in transition zones.

White spruce is found in mid-slope areas, usually associated with seepage habitat types in moist forest sites, while aspen can be observed in local seepage areas in the lower part of the basin.

Non-Forest Cover

The non-forest plants are small trees, shrubs, grasses, herbs, and mosses. Associations of these habitat types within the basin are the same as those discussed for the general region.

The seepage plant associations characterize forest sites where interflow (water moving laterally through the soil above the water table) or sometimes groundwater flow intersects the land surface, or is very close to it. These seepage plant varieties are found on approximately 22 per cent of the basin surface (Map 3).

In the lower part of the basin, pine grasses (Calmogrostis rubescens) are

found under young lodgepole pine forest in dry sites, while horsetail (*Equisetum*) is found in moist sites (R.T. Ogilvie, 1967, written communication).

Higher in the basin menziesia and club moss (*Lycopodium*) are found under the spruce-fir canopy in dry sites. The moist sites can be divided into two types. In the most severe case where groundwater seepage and interflow are ponded a "hangmoor" * develops. Thick mosses (*Sphagnum-Ledum* type) are found in the wet central area surrounded by sedges (*Carex*). White spruce (*Picea glauca*) is the associated forest type.

In the better drained areas where seepage is near the surface, as along stream channels and on gentle slopes, horsetail and dogwood (*Cornus*) are found.

In the alpine zone (above 6,500 feet) grouseberry (*Vaccinium scoparium*) inhabits the dry sites, with horsetail and moist herb meadow types included in moist sites.

In the snow-pack areas of the alpine tundra zone moist herb meadow is found, whereas the dry meadow types cover the less sheltered, drier area.

Soils

The soils of the Marmot Creek basin are presently being studied in detail and classified by G.J. Beke for the Forest Research Branch, Canada Department of Forestry, as part of the "basin inventory". Therefore, only a general description taken largely from an internal report by Peters and Lindsay (1963) and supported by unpublished material from G.J. Beke is presented here (Map 3). The main soil types found in the Marmot Creek area are: Brunisolic Grey Wooded soils, Podzolic soils, Regosolic soils, Alpine Black soils, and local Gleysolic and Organic soils. The sequence of soil development appears to be controlled by elevation, parent material, and slope and moisture conditions.

Generally the Brunisolic Grey Wooded soil is found under the lodgepole pine forest in the lower part of the basin. Podzolic soils are found in the mid-slope areas under spruce-fir cover, Brunisolic soils under the spruce-fir forest at higher elevations than the Podzols, and Alpine Black soils in the alpine zone. Regosols are developed

*A local depression formed on slopes where seepage water is trapped. The plant types are phreatic and the soil types are thick organic peats (Crossley, 1951).

on rock and colluvium.

Thick Organic soils have developed in local depressions or hangmoors in the more gently sloping basin mid-slope areas where seepage is ponded. Gleysolic soils have developed in drained seepage areas along creek banks and in areas where the slope is gentler.

Bedrock Geology

Stratigraphy

The bedrock underlying the Marmot Creek basin consists almost entirely of Mesozoic rocks (Map 4). Paleozoic rocks are exposed at the basin outlet where Marmot Creek has cut a deep gorge into the Rocky Mountain quartzites of Permian age (Plate II). These quartzites and the underlying hard, cherty dolomites of the Rocky Mountain Group form a distinctive bench underlying the basin area between Ribbon and Lorette Creeks.

The Spray River Formation of Early Triassic age lies on the erosional surface of the Rocky Mountain Group (Crockford, 1949); this erosional contact was not observed in the map area. The Spray River Formation consists of dark grey, carbonaceous, pyritic shale at the base (from borehole cuttings) overlain by hard, platy siltstones and shales. Higher in the formation the siltstone beds are flaggy and appear as "talus shingles" below steep cliffs. These brown weathered, flaggy siltstones form the steep cliffs along the north bank of Marmot Creek in the confluence area. Generally, the siltstone beds are thicker toward the top of the formation and crop out as blocky to massive-bedded siltstones at the Marmot Creek and Cabin Creek confluence and along the lower part of the Cabin Creek channel. These Spray River strata underlie most of the confluence area and the lower part of the Cabin Creek sub-basin, being expressed topographically as rounded hogbacks or steep cliffs along stream channels.

Overlying the eroded surface of the Spray River are the black fissile, poker-

chip shales of the Fernie Formation. These shales are covered with till in the Marmot Creek basin but can be observed along Ribbon Creek.

Approximately 100 feet above the base of the Fernie Formation a thin layer of very calcareous, silty limestone known as the Rock Creek Member, contains a fossil suite of Bajocian age (Warren, 1927). This member was not observed in the Marmot Creek basin, although boulders from it appear in the Cabin Creek channel. The Rock Creek Member crops out in Ribbon Creek and on the saddle to the north of the basin. Overlying it is 100 feet of black, splintery shale, concealed within the basin.

The next marker bed of the Fernie Formation is the Pigeon Creek member. This member consists of 120 feet of dark grey, calcareous, blocky, fine-grained sandstones and crops out at the confluence of the Cabin Creek tributary streams. A concretionary zone overlies the Pigeon Creek member and consists of 450 feet of dark grey shales including thin bands of rusty weathered ironstone concretions and argillaceous sandstones. Part of this zone crops out in the Cabin Creek channels.

Above the concretionary zone, sandstone beds are more numerous and thicker toward the top where they are cross-bedded and massive. These brown weathered, argillaceous sandstones are known as the "Passage Beds." The contact between the Passage Beds and the overlying massive, salt-and-pepper sandstone of the Kootenay Formation was observed in the Ribbon Creek area below the Kananaskis coal mine; sedimentation appears to have been continuous.

The basal Kootenay sandstone and the underlying Passage Beds form a discontinuous "step", or ridge across the Marmot Creek basin. For ease in mapping, these conformable sandstone beds were considered as a unit.

Overlying the basal sandstone bed, the lower shale member of the Kootenay Formation includes a predominantly shale-coal sequence with argillaceous sandstone beds commonly dividing the shales. The lower shale member has an average thickness around 1,000 feet in the Marmot Creek area and underlies much of the basin mid-slopes.

Overlying the lower shale member is the upper sandstone member of the Kootenay Formation consisting of approximately 1,800 feet of interbedded sandstone and shale, interrupted at irregular intervals by thick, medium- to coarse-grained, cross-bedded sandstones. The upper sandstone member underlies most of the steep alpine part of the Marmot Creek basin (Plate III) .

The topmost member of the Kootenay Formation is the Pocatererra Creek member which includes about 350 feet of interbedded sandstone and shale with thin beds or lenses of conglomerate. This member combines with the thick, massive, overlying conglomerate beds of the basal Blairmore Formation to form a resistant cap, locally preserving the area as a bedrock high. These thick sandstones and conglomerate beds form a distinctive marker unit to outline the Mount Allan Syncline. The core of the syncline contains about 900 feet of interbedded sandstones, shales, and conglomerates of the Blairmore Formation.

Structure

The Mesozoic rock succession underlying the Marmot Creek basin makes up the shallow-dipping east limb of the Mount Allan Syncline, the core of which is exposed on the topographic saddle dividing the two major cirques of Mount Allan (Map 4). The back limb of the overturned syncline forms the peak of Mount Allan.

Two thrust faults appear to cross the Marmot Creek basin. The first of these is the Spray River Formation, faulting Spray River on Spray River in the confluence area and Spray River on Fernie on the topographic saddle to the north. This fault can be observed crossing the small stream immediately south of the basin and at the break in the north slope along the Marmot Creek channel by the old sawmill site. The second fault of noted extent crosses the Marmot Creek basin within the upper Kootenay sandstone member. This fault has been observed along the headwaters of Cabin Creek and along Ribbon Creek, and may be the cause of the increased width of outcrop of the upper Kootenay sandstones to the north. Two thrust faults of un-

known extent have been observed within the Spray River Formation along the lower reaches of the Cabin Creek channel (Map 4). The upper fault has associated drag folds along a crushed fault zone, indicating some significant movement, while the lower fault plane contains "slickensides", or grooves that strike N 70° E. Because of the blocky nature of the beds above and below the faults, the amount of throw is conjectural.

Zones of local occurrence of highly contorted folds and faults are found in the sections of Mesozoic strata along Ribbon Creek. Transverse and normal faults can be seen within the upper Kootenay sandstones of Marmot Creek basin and within the Spray River Formation along Ribbon Creek.

Well developed joint sets are characteristic of the Rocky Mountain Group and the overlying Spray River siltstones. The dip and the line of intersection of these joint sets is generally normal to the bedding planes. Their orientation is shown on Map 4. The directions of stream flow in the lower part of Cabin Creek are similar to the directions of the better developed joints, suggesting that the streams cut their courses along lines of weakness caused by the presence of the joints.

Surficial Deposits

Generally, surficial deposits cover the major portion of the Marmot Creek basin area with bedrock cropping out at high elevations around the resistant structural cap of Mount Allan and along creek channels in the lower elevations:

The surficial deposits can be divided into two general groups: glacial deposits (including glaciofluvial deposits) and postglacial deposits.

Glacial Deposits

Glacial deposits are tills, and glaciofluvial materials. The tills of the area were subdivided largely on the basis of the following criteria: location and topographic expression, presence or absence of carbonate erratics, and association with glacial erosional features. Observations were made of till thickness from boreholes, along stream channels and roadways, and by topographic projections on map sections.

Laboratory analyses have not been carried out as yet but till samples from 35 plots within the basin are being analysed as part of a separate study. Further samples will be collected for analysis from selected plots during 1967. These samples will be collected at spaced intervals from surface to bedrock during a cable-tool drilling program.

Three types of till were outlined on the map as follows: (1) local cirque moraines, including lateral moraine and hummocky disintegration moraine (Plate I); (2) Kananaskis Valley morainal ridges with associated erratics and striated boulders; and (3) Kananaskis Valley till lying between the morainal ridges.

The till in the cirque consists of clay and silt with sandstone and conglomerate boulders derived from the lower part of the Blairmore Formation. The calcite content appears low from visual examination. These materials also make up the thick deposits within the nivation hollows in the Twin Creek sub-basin alpine zone.

The Kananaskis Valley morainal ridges crossing the basin could be recessional moraines marking position of equilibrium of the downwasting Kananaskis Valley glacier. These moraines are sectioned by crossing streams and have apparent thicknesses up to 100 feet in places. Part of this material may be slumped over or cored with bedrock. The estimated thicknesses represented on the map by contours are believed to be conservative. This material reacts with dilute hydrochloric acid and contains a high percentage of limestone and quartzite boulders; it is classified as having a high carbonate content.

The Kananaskis Valley till lying between the morainal ridges contains a higher percentage of local materials (siltstone, sandstone, and shale) suggesting that this till was formed under the ice from the underlying materials. Drill cuttings from boreholes in these areas show a paucity of the light grey limestone fragments that characterize the morainal ridge areas. The carbonate content of the surficial materials in these areas is expected to be lower than that of the morainal ridges. The areas between the ridges are locally covered with colluvial materials, mud

flows, and sheet wash.

Till and outwash in the lower confluence area form a large fan-shaped deposit of clay and boulders, with local gravel lenses. Drilling samples from boreholes drilled into this deposit include all of the rock varieties of the Kananaskis Valley tills.

Postglacial Deposits

Postglacial deposits are talus and scree (colluvium), alluvium, alluvial fans, and lag deposits in stream channels.

Talus is generally found as gravity deposits below steep bedrock ridges, whereas scree covers much of the slopes above the tree line. These deposits are composed of weathered fragments of local bedrock (sandstone, siltstone, and conglomerate in Marmot Creek basin).

Alluvium is found in the lower part of the map-area where small streams encounter local depressions with a resultant reduction in gradient. This material consists of fine sands and silts, with small patches of gravel at the breaks in slope.

Two large alluvial fans are shown on the lower portions of the map-area where Marmot and Ribbon Creeks reach the Kananaskis River flood plain. These materials vary in size from coarse sand to boulders.

Coarse angular boulders fill the valley bottoms along extensive reaches of the Marmot Creek stream channels. These deposits appear to have an average thickness of around 25 feet in the sub-basins, increasing to 60 feet in the lower confluence area. These coarse boulders appear to have been brought into the stream channels by slump, mud flow, soil creep and rock avalanche where the finer materials were washed out. The residue materials are referred to as "lag deposits".

GEOLOGIC INFLUENCES ON HYDROLOGY

Bedrock

The bedrock out of which the drainage basin has been carved consists of siltstone, shale, interbedded sandstone and shale, coal, cross-bedded sandstone, and conglomerate.

These strata lie on the erosional surface of a thick quartzite that comes to the surface and forms a prominent topographic bench at the mouth of the basin. The main weir is cemented into this quartzite and measures the total streamflow draining from the basin.

These rock units from outcrop and thin section examination (Plate V) are well indurated and well cemented with negligible intergranular porosity. All strata appear to be jointed and locally folded and fractured in varying degrees. These fractures, if persistent and open at depth, may be significant in the storage and movement of groundwater.

The quartzite of the Rocky Mountain Group housing the main weir shows irregularly distributed joints; in outcrop sections these joints show no crystallization or weathering on the surface and are believed to be closed at depth. This latter conclusion is supported by comparison of hydrographs of piezometers installed within the weathered surface of the quartzite (Site S265 P-RM123) and deeper into the bedrock (Site N320 P-RM47) (Map 6). The following groundwater installations are located at site S265: piezometer S265 P-RM123 is completed in fractured bedrock at a depth of 123 feet; piezometer S265 P101 is completed in stony till at a depth of 101 feet; and the water-table observation well S265 WT40 is completed in stony till at a depth of 40 feet. The hydrographs of these three installations (Appendices A and B) show similar fluctuations indicating the saturated materials are acting as a hydraulic unit.

The following groundwater installations are located at site N320: water-table observation well N320 WT/RM8 is completed in stony till at a depth of 8

feet; water-table observation well N320 WT-RM38 is completed in stony till at a depth of 38 feet; piezometers N320P/RM28 and N320Pp/RM28 are completed in stony till at a depth of 28 feet; and piezometer N320 P-RM47 is completed in solid bedrock at a depth of 47 feet. The hydrographs of the installations completed in the surficial materials show comparable fluctuations and indicate the surficial materials are acting as a hydraulic unit. The hydrograph of the Piezometer completed in solid bedrock does not fluctuate with the hydrographs of the more shallow installations indicating that the water pressure within the bedrock does not change with a change in the water head in the overlying surficial materials. If piezometer N320 P-RM47 represents the hydraulic conditions in the bedrock, then the bedrock (quartzite of the Rocky Mountain Group) can be considered hydraulically disconnected from the surficial material and relatively impermeable.

Thin-bedded to massive siltstone of the Spray River Formation, underlying most of the confluence area and the lower part of the Cabin Creek sub-basin, show one or more well-developed joint sets. Although these joints show no crystalization or weathering, they appear to have exerted some control in the development of the lower part of the Cabin Creek channel. A piezometer (S400 P-SR32) was developed within the siltstone bedrock and a water-table observation well (S400WT-SR26) was developed in the overlying surficial materials. The hydrograph of S400 WT-SR26 responds to climatic events, while the hydrograph of the piezometer indicates the bedrock is hydraulically disconnected from the overlying surficial materials. Additional installations will test the validity of this conclusion.

A piezometer (S835 P-F47) was developed in the fractured shales of the Fernie Formation. The hydrograph of this installation shows a response to climatic events, indicating a hydraulic connection between these shales and the overlying surficial materials. A pumping test was not successful because of technical difficulties.

No observation wells or piezometers are developed within the Kootenay shale or sandstone members. The lower shale unit of the Kootenay Formation is similar in

lithology and intensity of jointing to the shales of the Fernie Formation and, therefore, may have fracture permeability similar to that of the Fernie shales.

The upper sandstone and conglomerate rock units of the Kootenay and Blairmore Formations underlie the upper parts of the sub-basins where the surface gradients are steep. These steep slopes suggest that the greater part of precipitation in these regions is converted to surface runoff and shallow lateral flow parallel to the surface gradients.

In summary, quartzite of the Rocky Mountain Group housing the main weir is relatively impermeable, eliminating underflow. The Spray River siltstones overlying the quartzite may have significant local fracture permeability. The fractured shale units of the Fernie and Kootenay Formations probably contribute most to the storage and movement of groundwater within the bedrock materials.

Surficial Deposits

The surficial deposits within the basin area include glacial deposits and post-glacial deposits (Map 5).

Glacial deposits cover the major part of the basin area and consist mainly of a mantle of stony till. This till is approximately 30 feet thick over most of the confluence area, whereas above the confluence area morainal ridges consisting of thick till are found. A water-table observation well, S1170 WT/K47 is completed in a moraine ridge at a depth of 47 feet; the water level in this well fluctuated rapidly in response to climatic events.

Water-table observation wells S400 WT-SR26, S570 WT-SR29, S685 WT-SR32, N820 WT-SR20, N900 WT-SR24, N1080 WT-SR20, and N1200 WT-SR22 are completed in the mantle of stony till covering the Spray River siltstone in the confluence area. The water levels in these wells all fluctuate rapidly in response to climatic events indicating the till mantle has a high infiltration capacity and a low water retention capacity.

In the lower part of the confluence area a thick fan-shaped wedge of till is

found. The hydrograph for the water-table observation well N475 WT-RM120, completed in this moraine, fluctuates in response to climatic events but the fluctuations are several times smaller than those for the wells completed in tills over adjacent highs. At the lower end of the moraine a bulldozer has cut through a ridge of till exposing a gravel lense and starting a permanent spring. In the cirque area lateral moraines and hummocky moraines are found. No observation wells have been completed in the cirque moraines, however, spring water seeping from the base of scree slopes is locally trapped on the cirque floor, indicating that the tills in the cirque have a moderate to high water retention capacity.

The postglacial deposits include talus, built up below rock cliffs and ledges (Map 5), and scree slopes found over much of the alpine zone. The colluvial materials generally have a high infiltration capacity but low moisture storage and retention capacity.

Log deposits, retained in the V-shaped stream channels are saturated since the streams flow over and around them. Their storage capacity changes little in the way of bank storage, as is indicated by the relatively stable hydrograph of observation well M300 WT/RM16 located at the Marmot Creek channel level.

Natural Groundwater Movement

Generally, the phreatic divides of the Marmot Creek basin are close to the topographic divides. In the upper parts of the basin, where the slopes are very steep and the surficial material is more permeable than the underlying bedrock, the direction of flow of groundwater and vadose* water generally parallels the slope of the topography. This water is never very far below the land surface and where the slopes are abruptly gentle groundwater seepage or springs "crop out", such as those found along the upper stream channels (Map 3).

Lower in the basins where the slopes are more gentle and the bedrock more

*Vadose water is water in the zone of aeration (Meinzer, 1923), including capillary fringe water, intermediate vadose water, and soil water.

permeable and hydraulically connected to the surficial materials, the direction of groundwater flow is downward away from the land surface as in the recharge area of the classic flow system (Tóth, 1962). Where these flow paths encounter resistant sandstone members such as the basal Kootenay sandstone, some of the groundwater flow is deflected back toward the surface where it is discharged in the form of seeps, springs, and evapotranspiration. Lower in the basin at the top of the Spray River siltstone, more groundwater is deflected back toward the surface and locally discharged.

Elevations of points on the water table where the water table intersects the land surface, such as along stream channels, at contact springs, and seeps may be obtained from their locations on topographic maps. The elevation of the water table in observation wells may be obtained from the groundwater hydrographs. A water-table contour map (Fig. 8) was constructed for June 30, 1966 from the elevation control mentioned above. Small 1/2 inch diameter piezometers were driven by hand in local areas to check the positions of phreatic divides and to test areas of upward flow of groundwater.

Generally, the flow of groundwater within the Marmot Creek basin is an unconfined system to which water is added in spring and early summer from rainfall and snowmelt, and from which water is continuously removed by seepage, and evapotranspiration. The level of the water table rises and falls in direct response to precipitation. The fluctuations shown on most of the hydrographs of the groundwater observation wells can be related directly to the fluctuations on the streamflow hydrographs.

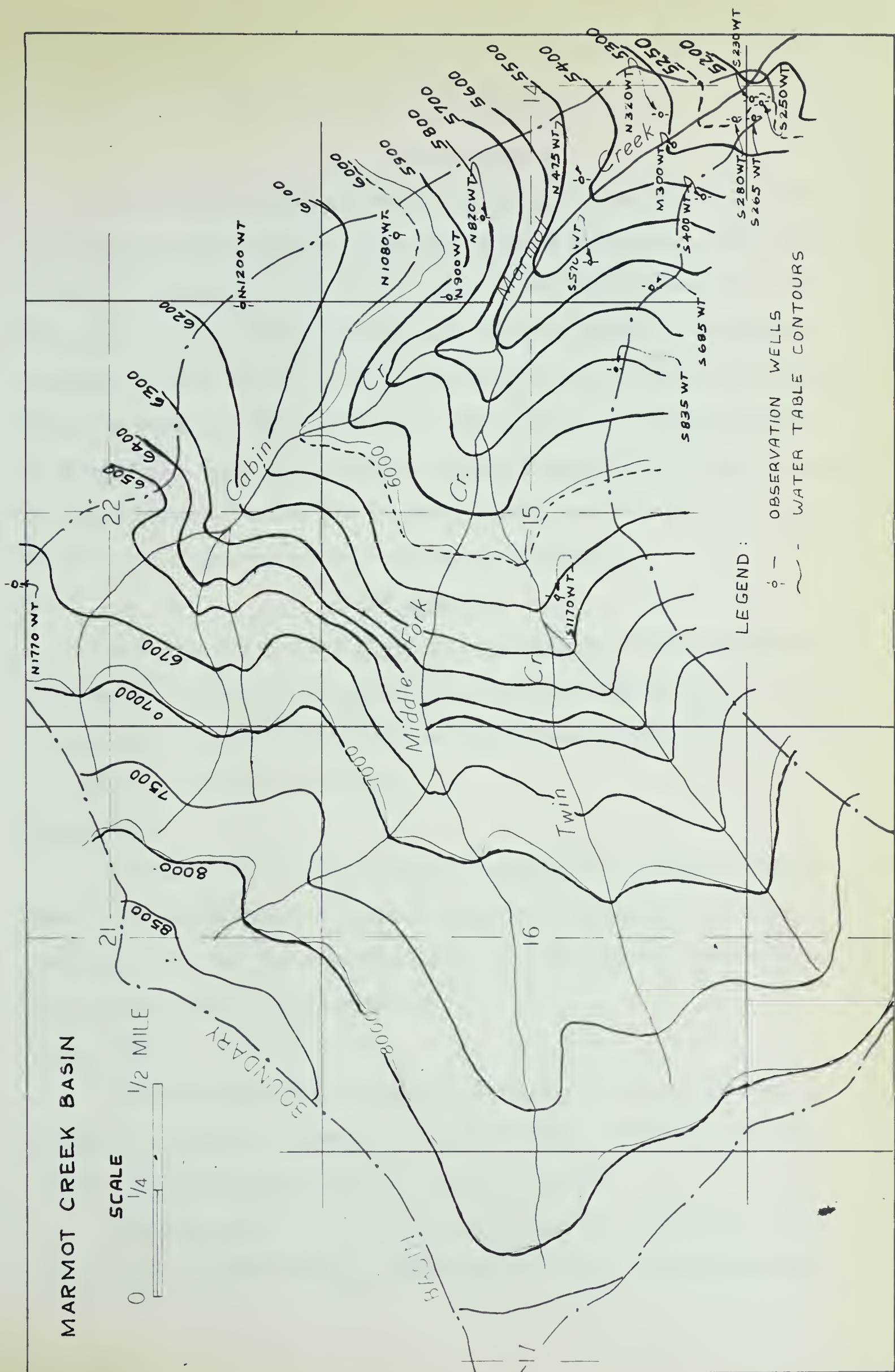


Figure 8. Water Table Contour Map, June 30, 1966.

HYDROLOGY OF THE MARMOT CREEK BASIN

The Hydrologic Budget

The hydrologic budget of an area is a statement of water gains, water losses, and changes in water storage for the specified period of measurement. The budget is balanced by equating the water gain to the area to the water lost from the area plus the increase or minus the decrease in storage. The water gain to the area includes precipitation and water running into the area both above and below the land surface. The water lost from the area includes water running out of the area both above and below the land surface, water evaporated above and below the land surface, and water transpired by plants. Increases or decreases in storage occur when there is a change in the amount of water stored above or below the land surface.

Instrumentation

To measure the components involved in the hydrologic budget of the Marmot Creek basin, a program of instrumentation was initiated in 1962 and further developed through 1966. The main fields of instrumentation include meteorology, surface water, soil moisture, and groundwater (Map 6).

Meteorology

The meteorological instrumentation was carried out by the Meteorological Branch, Canada Department of Transport. Precipitation, temperature, wind, evaporation, humidity, and radiation are presently being measured on the Marmot Creek basin with instruments as listed in Table 3.

Surface Water

The Water Resources Branch, Canada Department of Energy, Mines and Resources, is responsible for gauging the streams, carrying out a sediment analysis, and collecting surface-water samples for chemical analyses.

Flow measurement stations are located at the outlets of the Marmot Creek basin (Marmot Creek Main Stem), the Twin Creek sub-basin, the Middle Creek sub-

Table 3. Meteorological Instrumentation in Marmot Creek Basin

Component	Instrumentation	Reading frequency	Period of Measurement	Remarks
Precipitation	8 Sacramento storage gauges 30 vertical MSC* gauges	Twice yearly Weekly	Continuous Summer months	Located in areas of difficult access Located to measure effects of slope, aspect, elevation, and exposure
Snow pack density and thickness	18 ten-point snow courses	Monthly from Jan. until spring snow-melt begins, then weekly until main snow pack melts	Winter months	Located to measure the effect of cover, slope, aspect, and elevation
Temperature	9 snow stakes 5 electric thermographs 4 maximum & minimum temperature thermographs 3 hygrothermographs 2 recording anemometers	Monthly Continuous recordings Weekly Weekly Continuous	Winter months Annual Summer months Summer months Summer months Annual	One located at the top of the basin, other at bottom of basin Located in confluence area Located in confluence area
Wind				
Evaporation	1 Class A Evaporation pan 3 hygrothermographs 1 radiometer	Daily Weekly Daily	Summer months Summer months Annual	One located at the top of the basin, other at bottom of basin Located in confluence area Located in confluence area
Humidity Radiation				

* Meteorological Service of Canada

basin, and the Cabin Creek sub-basin, as well as in the cirque area above Middle Fork Creek (Map 6).

The station at "Marmot Creek Main Stem", located in the main channel at the outlet of Marmot Creek basin, is a sharp-crested V-notch type (120 degrees) weir, having a 4.0-foot head and a maximum capacity of 150 cfs.

Sharp-crested V-notch weirs (90 degrees) have been located at the Twin Creek and Middle Fork sub-basin outlets. These weirs are the same type as the weir at Marmot Creek Main Stem, except that the head has been decreased in proportion to the flow (2.5-foot head with capacity of 19 cfs). Water levels in the weir ponds are obtained with hook gauges.

The stations at the Cabin Creek and cirque outlets are 2.5 foot head H-flumes. This type of flume is accurate at high and low flows (0.02 to 19 cfs.) and is self-cleaning at high flows. A manometer is located on the side of the float well to obtain accurate water levels. Stage-discharge relationships have been established.

All flow measurement stations are equipped with spring-driven Leupold and Stevens A-35 automatic water-level recorders; these recorders will detect changes in stage of 0.002 of a foot. All stream stations are equipped with cold-weather hoods heated with propane or electricity.

Depth-integrated, suspended-sediment samples are collected at the Marmot Creek Main Stem by means of a hand sampler. These samples are collected from the center of the stream on a daily basis during periods normally associated with high flows (April-November), and on a weekly basis during periods associated with low flows. Concentrations of dissolved solids and suspended sediments are measured. Bed load has not been measured to date.

Surface-water samples are collected weekly from the weirs and flumes of Marmot, Twin, Middle Fork, and Cabin Creeks and the cirque station during the summer months. Samples are collected from the Kananaskis River downstream from the Marmot Creek

confluence. During the winter months samples are collected monthly at the accessible stations.

Soil Moisture and Soil Temperature

Groups of Coleman units for soil-moisture measurement are located at six sites on the basin (Map 6). Each group consists of ten porous fibreglass sensors ranging in depth from the soil-humus interface to 72 inches. A thermistor is located with each sensor to record ground temperature. Resistance readings are taken weekly with a Beckman ohm-meter and converted to soil-moisture and temperature values.

Groundwater

During the 1964 and 1965 field seasons, 18 water-table wells and 8 piezometer sites were established in the Marmot Creek basin (Map 6). A drilling crew used a rotary drilling "rig" to drill the holes, set the casing and piezometer points, and flush the screens. The water-table wells were spaced over the accessible areas of the basin. The water-table observation-well casing is 4 inches in diameter, slotted and galvanized. The casing used initially was 4-inch steel casing slotted with an acetylene torch; this proved unsatisfactory because of corrosion.

The piezometers used were constructed of 2-inch steel pipe with a slotted point set in the open hole and "grouted in". Piezometers were installed in the various bed-rock units and in the gravel lenses of deep surficial deposits. Thirteen of the water-table wells and one piezometer are equipped with Leupold and Stevens type FM, weight-driven, continuous recorders with monthly charts; the remaining installations are measured on a weekly basis with a chalked steel tape.

Components of the Hydrologic Budget

The components involved in the hydrologic cycle and their interrelationships are shown in Figure 9. The hydrologic budget may be expressed in terms of these components by means of the hydrologic equation:

$$P = R + ET + \Delta S + U + L \quad (1)$$

in which

$$R = R_{sw} + R_s + R_g = \text{Streamflow},$$

$$ET = ET_{sw} + ET_s + ET_v + ET_g = \text{total evapotranspiration, and}$$

$$\Delta S = \Delta S_{sw} + \Delta S_s + \Delta S_v + \Delta S_g = \text{total change in storage}.$$

The symbols P , R , ET , ΔS , U , and L refer to precipitation, streamflow, evapotranspiration, storage-change, underflow, and basin-leakage components, respectively; and the subscripts sw , s , v , and g indicate those subcomponents associated with the surface-water, soil water, intermediate vadose water, and groundwater phases.

TOTAL EVAPORATION AND TRANSPIRATION

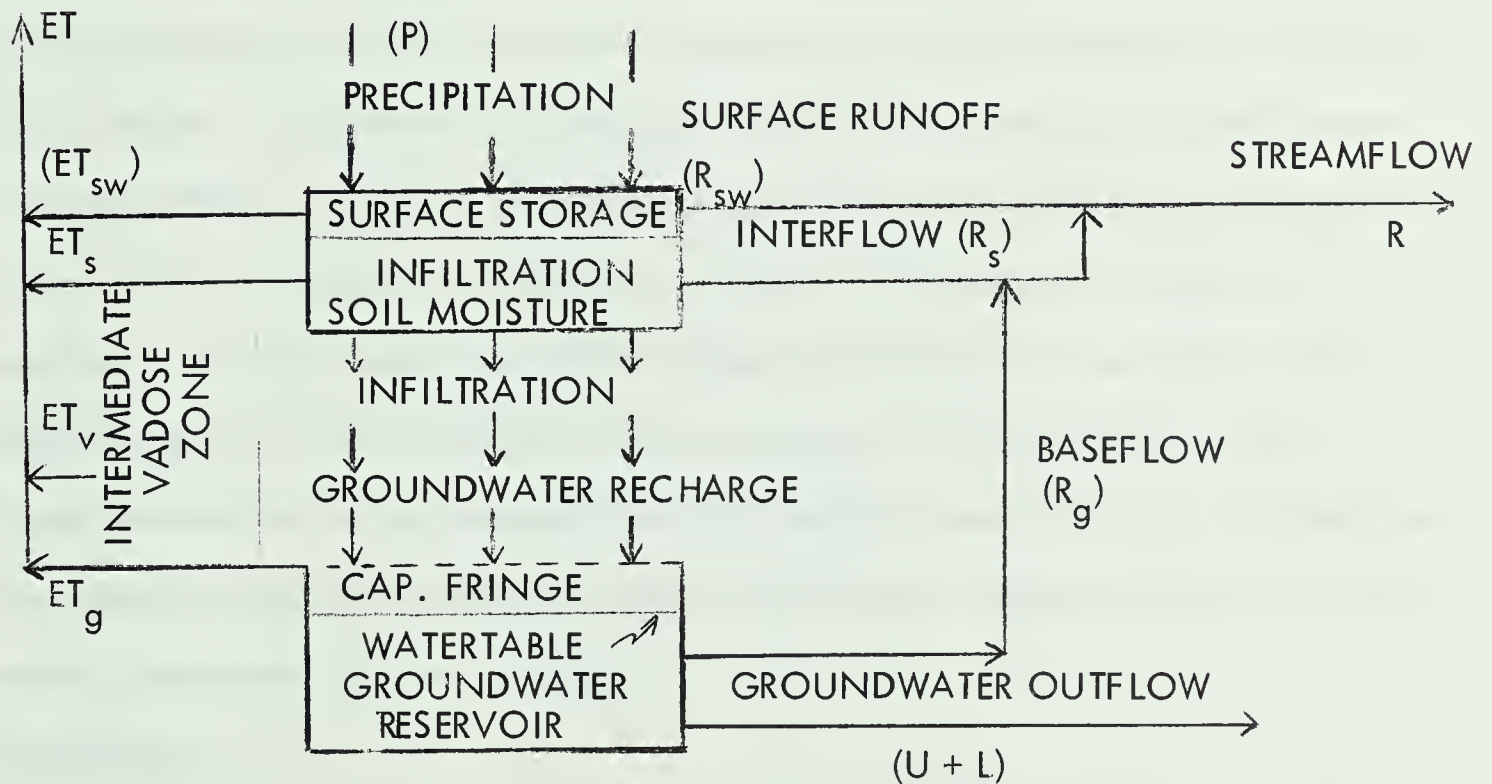


Figure 9. Schematic Diagram of the Components of the Hydrologic Budget

The surface runoff, R_{sw} , is sometimes referred to as overland flow and the soil water runoff, R_s , as interflow. Interflow takes place above the main water table and is thus distinguished from groundwater runoff, R_g , which takes place below the main water table and supplies the base flow of the stream during low flow recession periods.

Underflow is flow out of the basin under the main weir; it is believed to be negligible because of the relative impermeability of the foundation rocks under the weir. Basin leakage is groundwater flow into or out of the area at the topographic divides and should only assume importance if the phreatic divides do not coincide with the topographic divides. Figure 8 indicates that the two sets of divides coincide and it can therefore be assumed that basin leakage is negligible. With U and L both negligible, equation (1) can be restated:

$$P = R + ET + \Delta S \quad (2)$$

It is generally not possible to measure each subcomponent of the hydrologic cycle individually in order to arrive at a detailed quantitative statement of the hydrologic budget. It is nevertheless possible, in most cases, by selecting suitable measurement periods, to measure or estimate enough of the subcomponents or components to permit the derivation of a simplified quantitative statement of the budget. Measurements, estimates, and a hydrologic budget for the Marmot Creek basin for the period August 25, 1965 to August 25, 1966 are given in the succeeding sections. Evapotranspiration was not measured during the budget interval but is calculated from the hydrologic equation (Table 6). General discussions of observed variations of the various components are also included.

Precipitation

The precipitation network in the Marmot Creek basin is summarized in Table 3.

Although measurements obtained from the standard Meteorological Storage of Canada precipitation gauges show appreciable local variation in rainfall, they define a recognizable areal pattern (Figs. 10 and 11). There appears to be an increase in

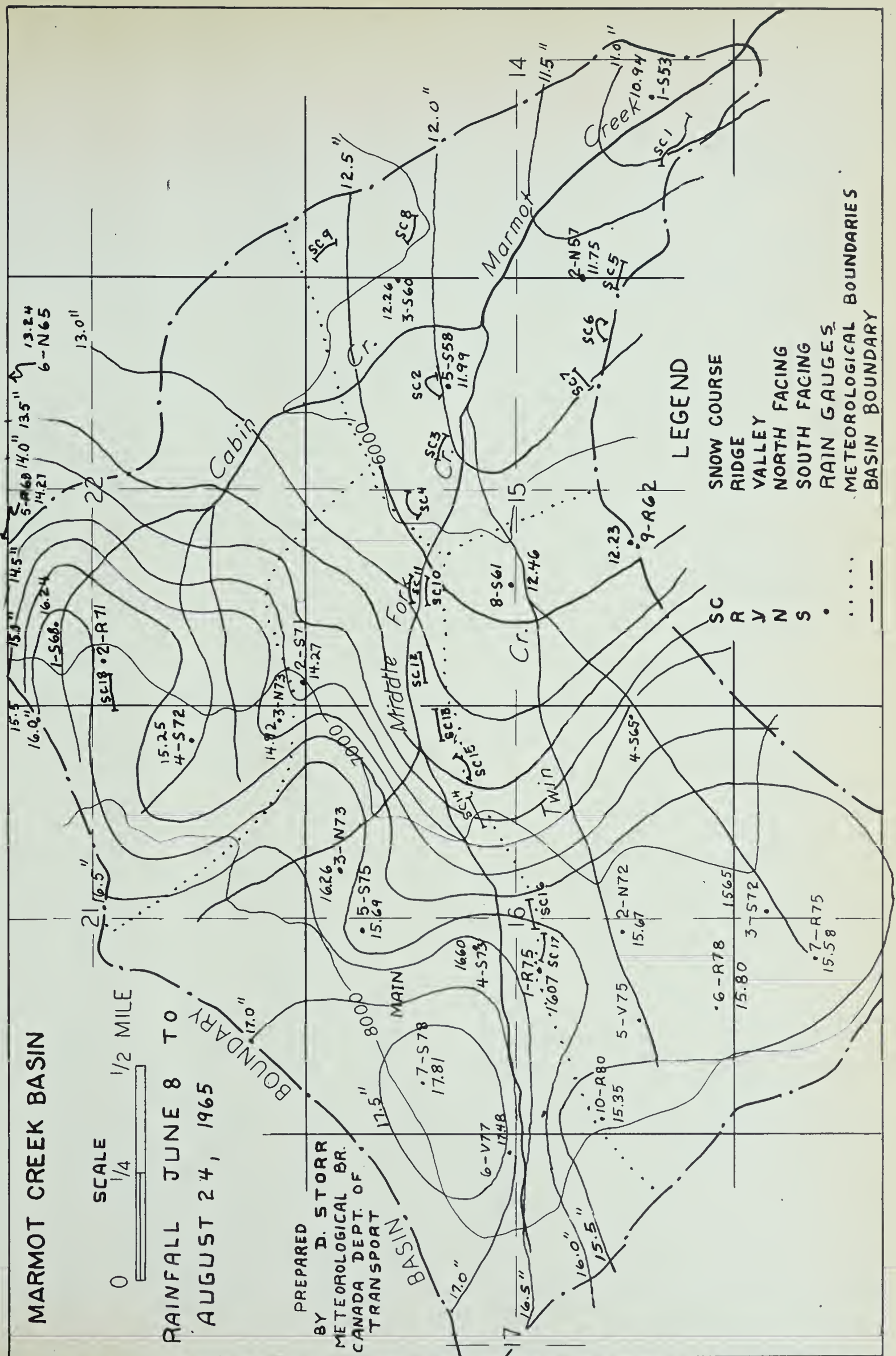


Figure 10. 1965 Summer Rainfall Distribution in Inches.



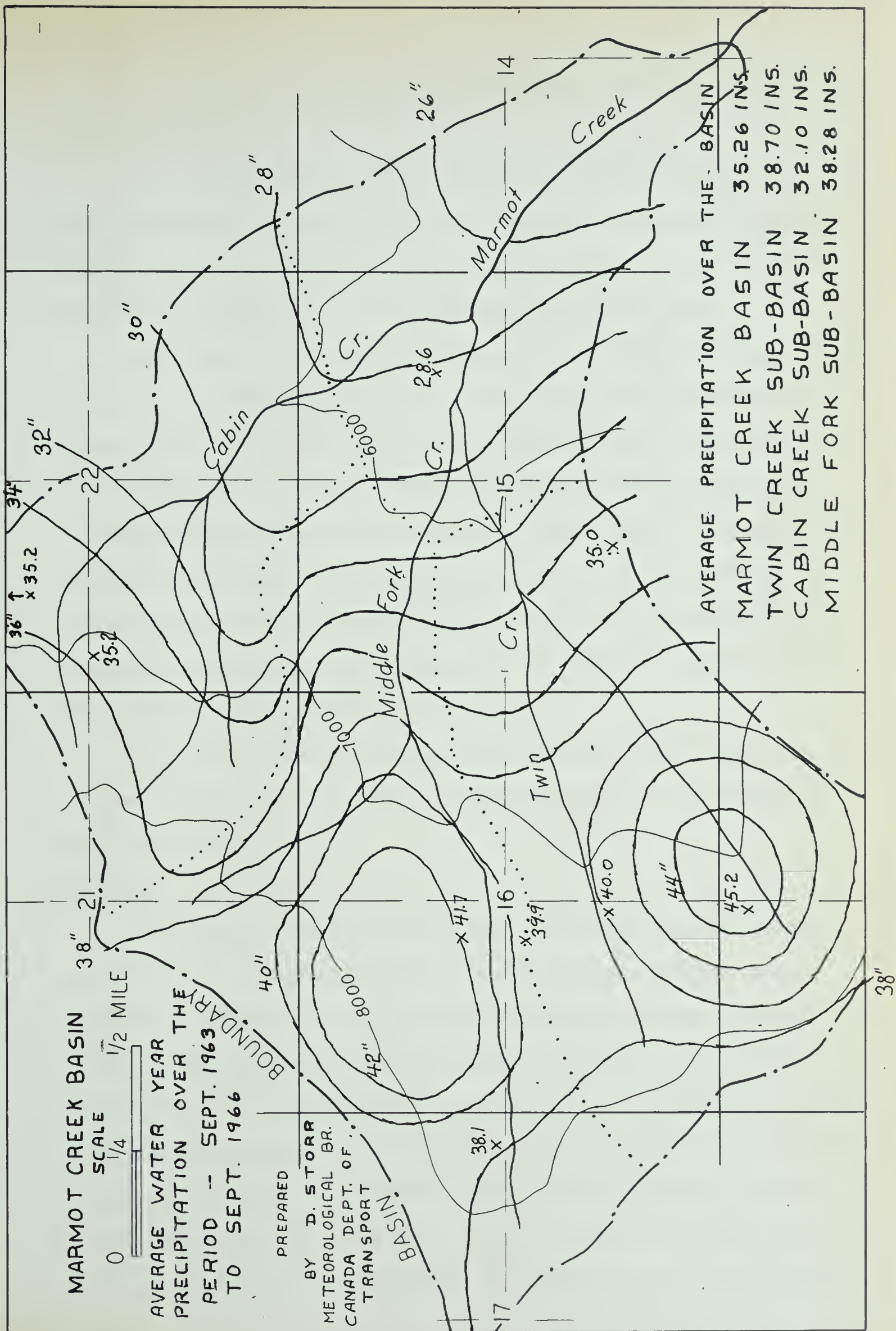


Figure 11. Average Water Year Precipitation in Inches.

rainfall with elevation of about 2.5 inches per thousand feet (D. Storr, 1967, written communication).

The annual precipitation pattern defined by the Sacramento gauges (Fig. 11) closely resembles the summer rainfall pattern. The precipitation pattern is greatly influenced by wind. Changes in wind direction may result in "spillover", where a storm center is shifted across the divide from one sub-basin to another.

In the Marmot Creek area 70 to 75 per cent of the precipitation occurs as snowfall or mixed snowfall and rainfall; part or all of the snowfall may be temporarily or seasonally stored on the basin surface. This snowfall is initially located by the precipitation gauge network, but snow drifting across basin divides and avalanching (avalanche tracks are common on the steep upper slopes of the Cabin Creek sub-basin) may appreciably alter the original distribution of snow. Late fall temperature fluctuations commonly cause the release of indefinite amounts of water through snowmelt to the normal processes of the hydrologic cycle. All of these factors make the short-term accounting of precipitation very complicated.

At the start and end of the budget period August 25, 1965 to August 25, 1966 there was no snow stored on the basin. Estimated precipitation for this period was 34.75 inches (Fig. 12).

Streamflow

Streamflow from the Marmot Creek basin is measured by the main gauge at the mouth of Marmot Creek. This location is called Marmot Creek Main Stem. Streamflow is a maximum in spring and early summer whenever a heavy spring rain follows a period of warm weather causing the winter snowpack to melt quickly. Minimum flow occurs in late March and is usually less than 1 cfs (Fig. 13). In early spring and summer, during non-rainfall periods, streamflow consists of base flow from basin storage, interflow, and snow melt. During midsummer snowmelt is derived from protected areas in the alpine zone. The cirque area above the Middle Fork sub-basin contributed approximately 70 per cent of the streamflow during the month

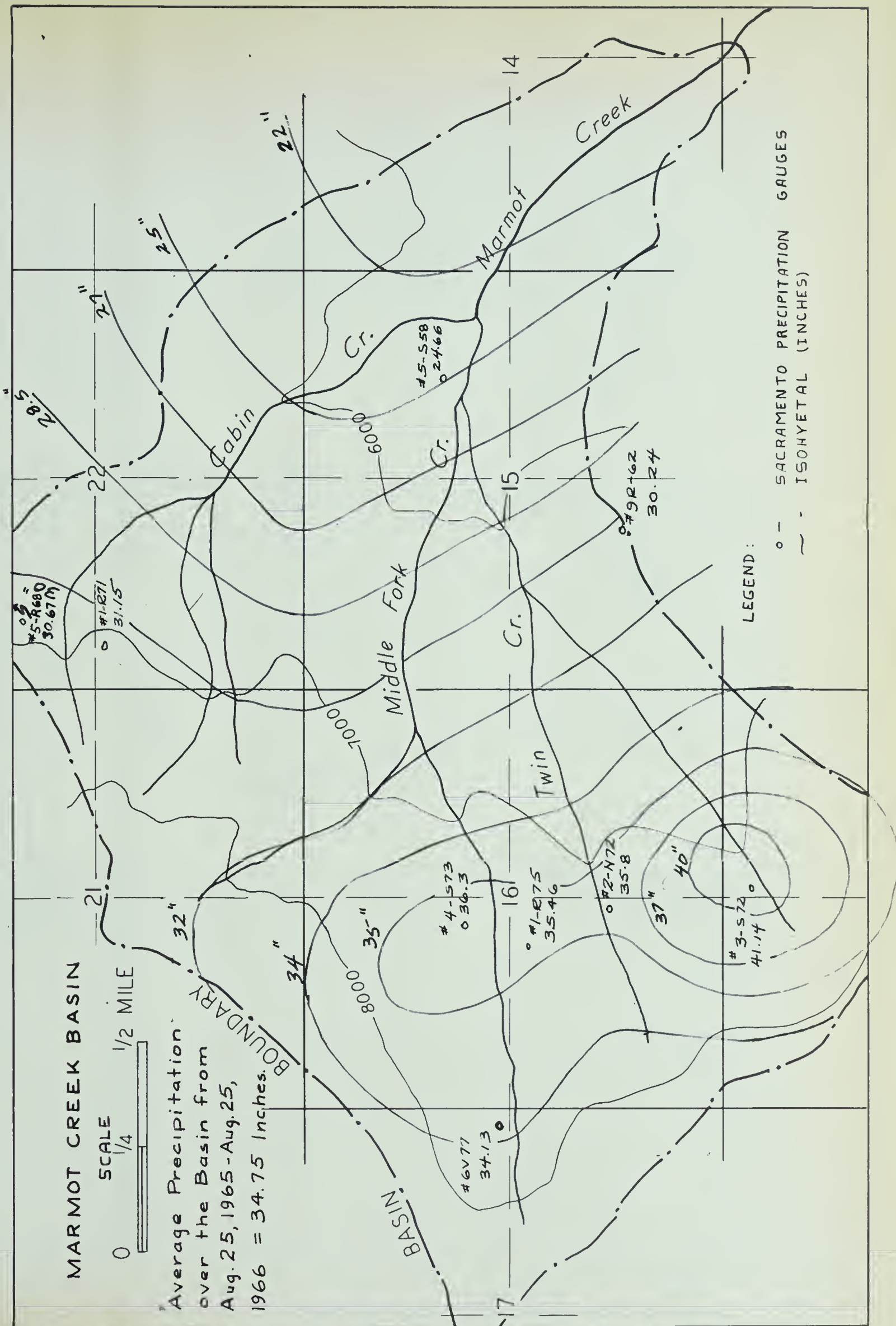
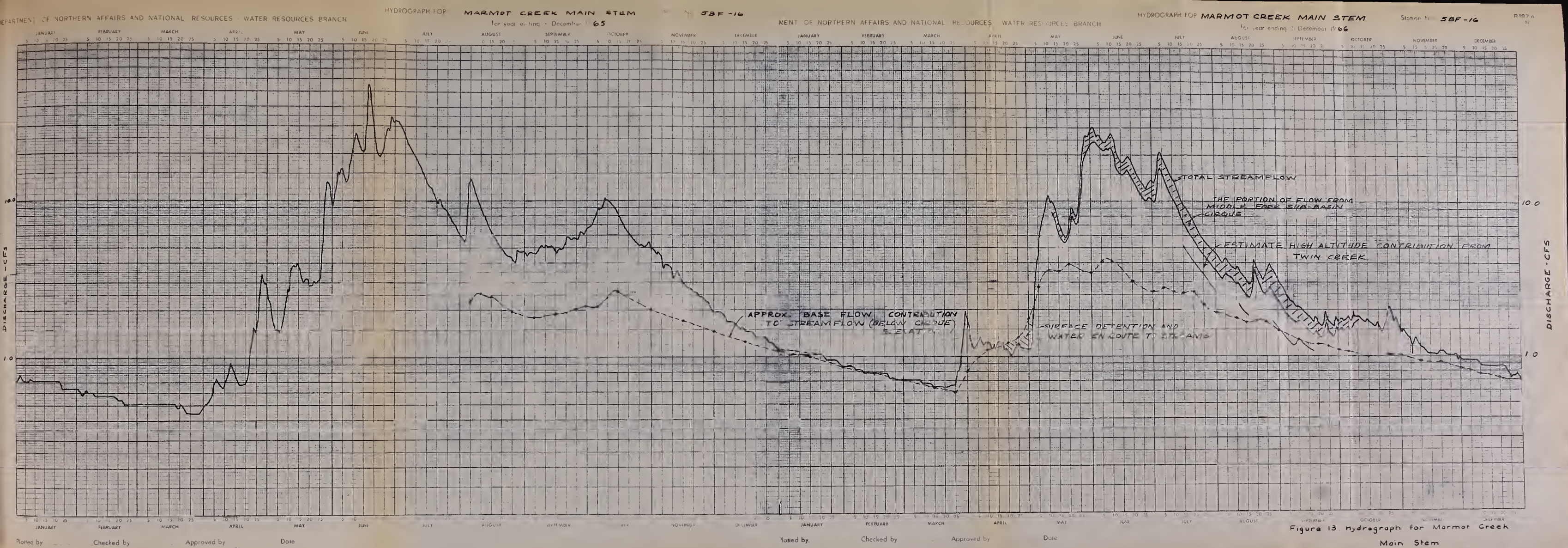


Fig.12. Average Precipitation Over the Basin for the Budget Period in Inches



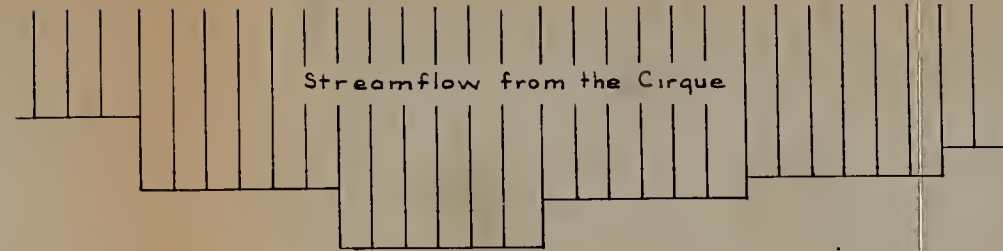
of July, 1966 (Fig. 14). The streamflow from the cirque appears to vary with rainfall during the summer and with temperature fluctuations during late fall. These fluctuations in temperature probably convert some snow to runoff.

The hydrographs of Middle Fork Creek and Twin Creek are very similar in magnitude and configuration (Fig. 16). It is noted that these two sub-basins have similar areas above the alpine zone. Similarly, the areas above the alpine zone of Middle Fork sub-basin (below the cirque) and the Cabin Creek sub-basin are nearly equal. Their stream hydrographs (Figs. 15 and 17) are also closely comparable.

During the months of January, February, and March, 1966, the hydrograph for Marmot Creek Main Stem is very close to a straight line on a logarithmic-time graph (Fig. 13). This straight line represents the approximate true baseflow contribution (Barnes, 1939).

The methods for separating base flow from streamflow during flood stages are not generally agreed upon. An empirical method relating the average recession of the water table over the basin to the recession of the stream stage during periods of no precipitation was used by W.C. Rasmussen and G.E. Andreason to separate base flow from runoff for a basin in Maryland (Rasmussen and Andreassen, 1959). R. J. Schicht and W.C. Walton used this method for basin studies in Illinois (Schicht and Walton, 1961), while F.H. Olmsted and A.G. Hely related overage groundwater stage to surface water for a basin study in Pennsylvania (Olmsted and Hely, 1962). In all cases the groundwater reservoir was recharged directly by precipitation and depleted in supplying base flow to the streams.

In the Marmot Creek basin the fluctuations of the groundwater hydrograph are caused by precipitation and are similar in configuration to the fluctuations of the stream hydrographs. A rating curve was prepared relating mean groundwater stage, calculated by averaging the water-table elevations for selected index wells, to base flow for Marmot Creek Main Stem during low-flow recession periods when the stream consisted entirely of base flow. This relationship is close to a straight line



Streamflow from Middle Fork Creek below Cirque

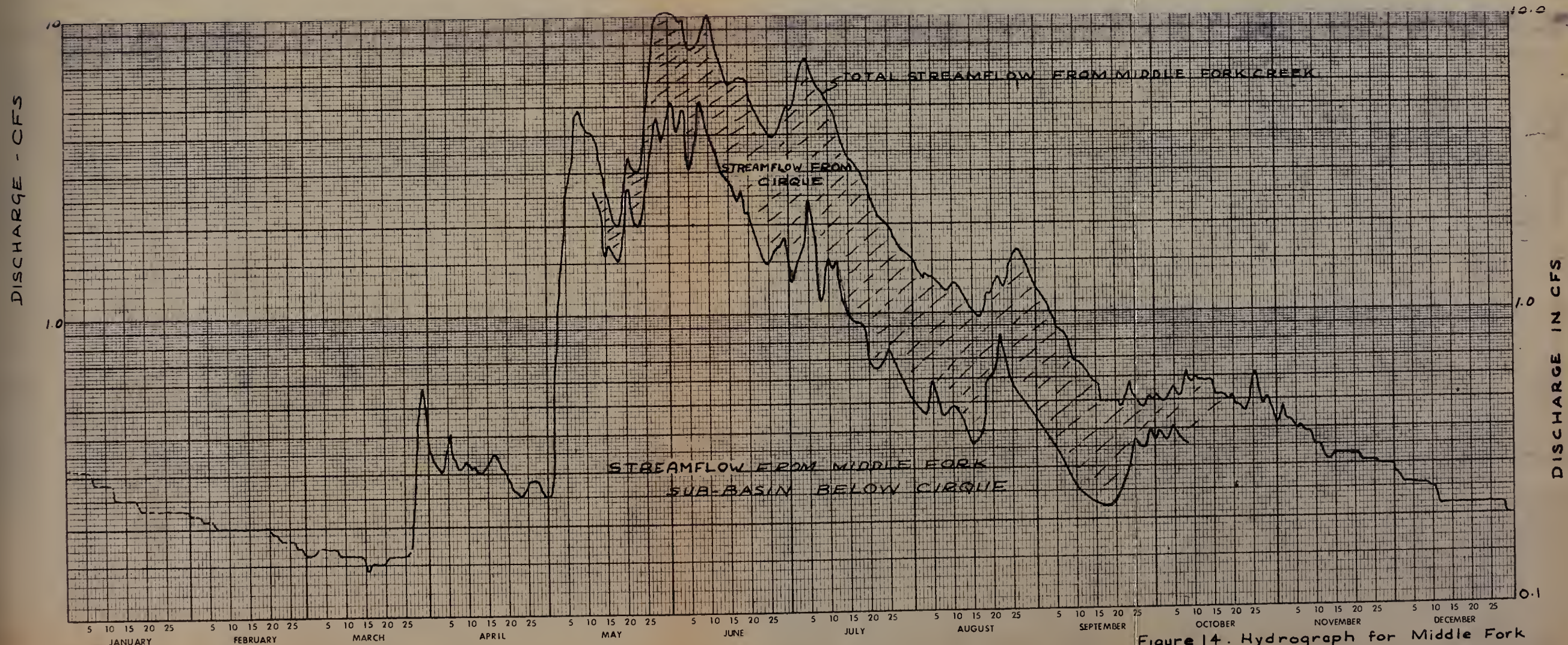
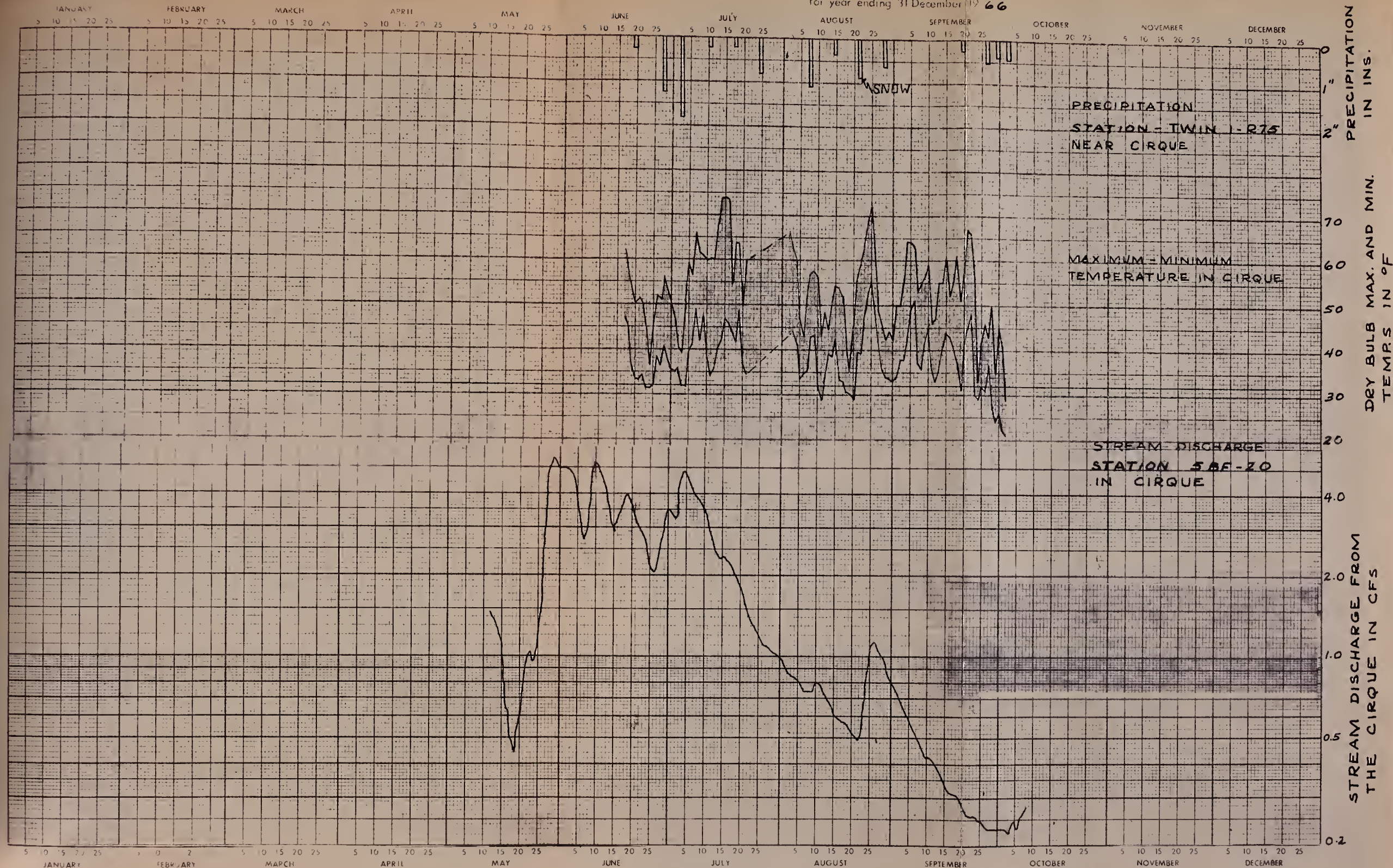


Figure 14. Hydrograph for Middle Fork Creek near Seebe

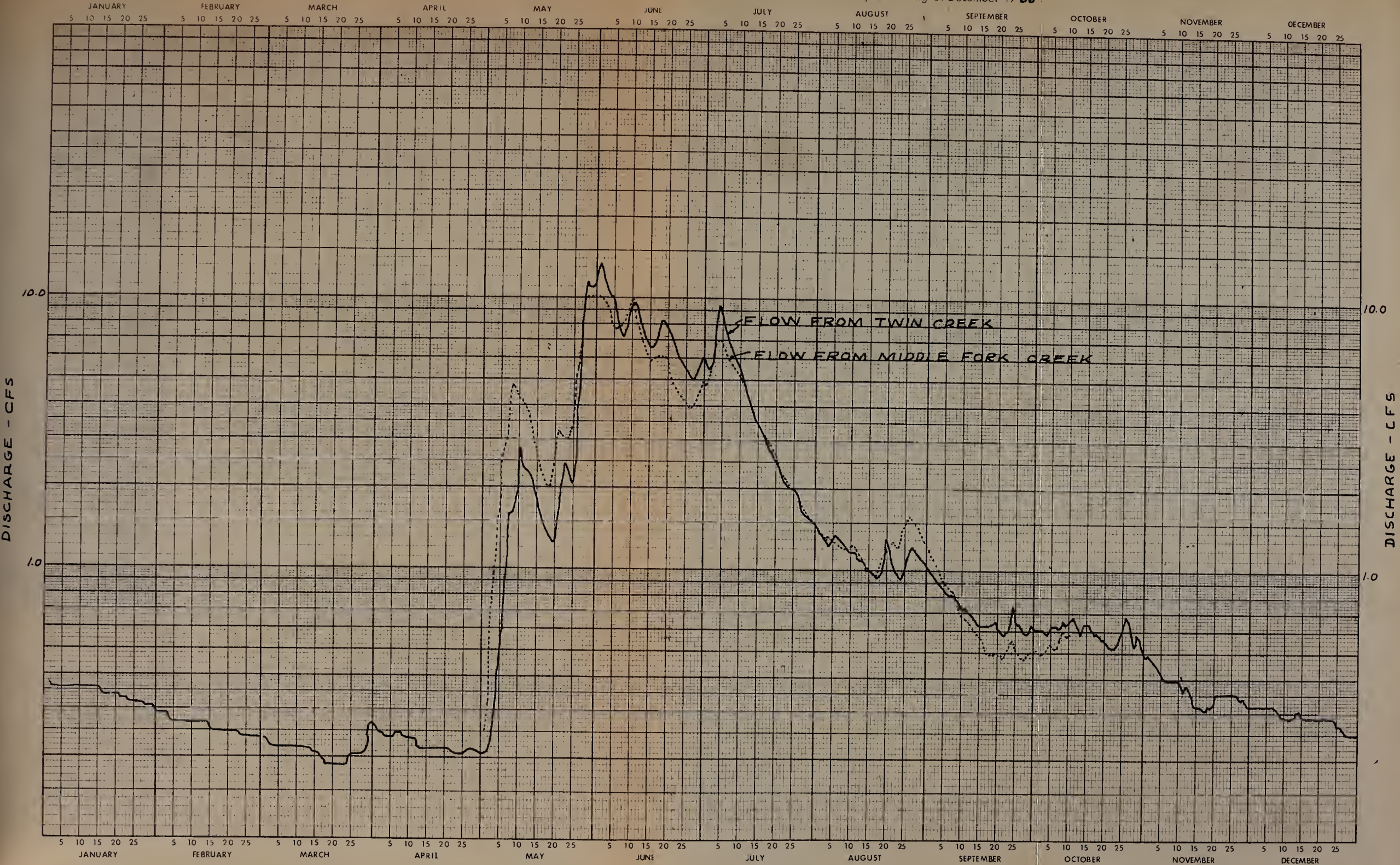
for year ending 31 December 19 66



Plotted by _____ Checked by _____ Approved by _____ Date _____

Figure 15. Hydrograph for Marmot Creek Basin (cirque)

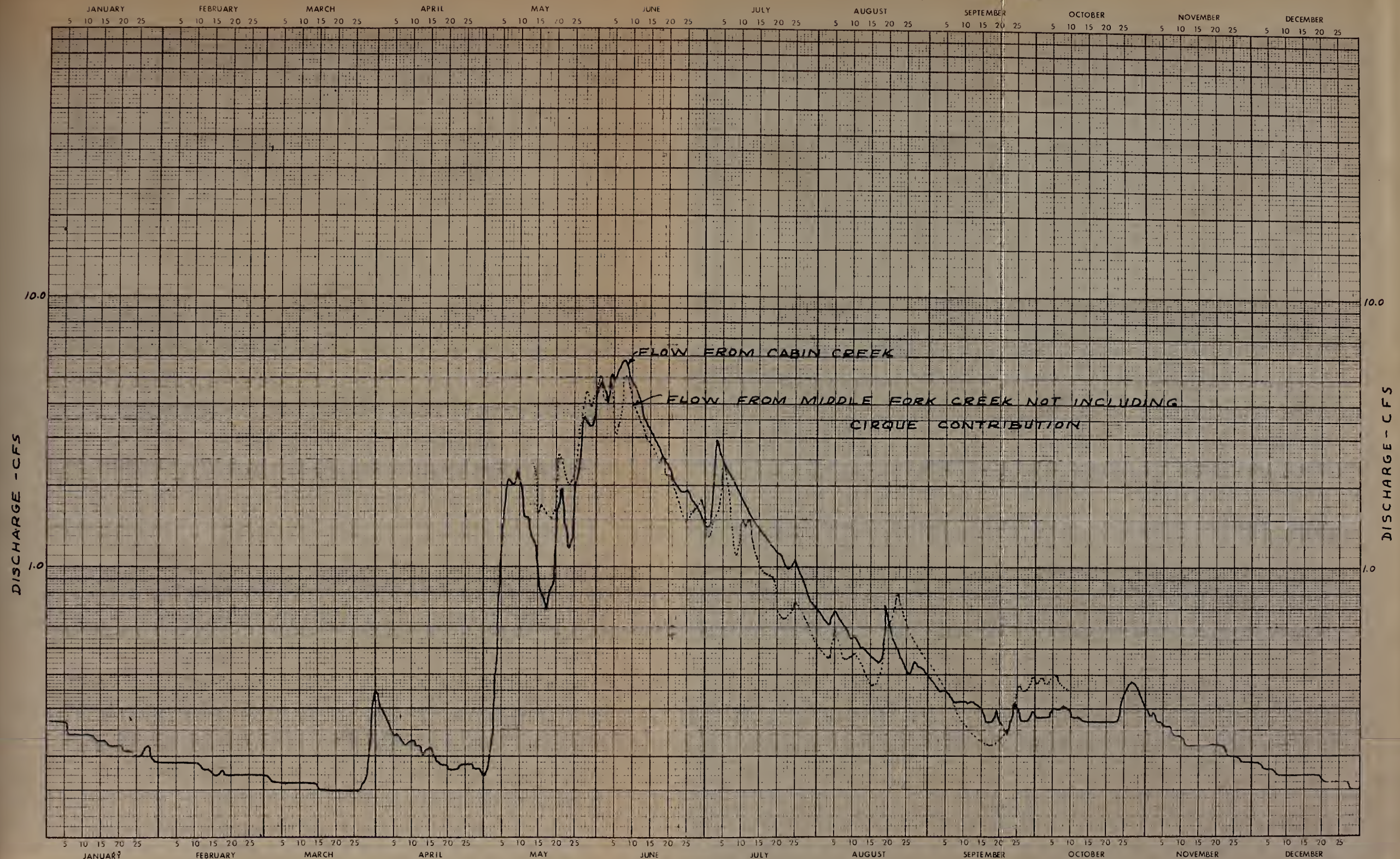
for year ending 31 December 1966



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Figure 16. Hydrograph for Twin Creek near Seebe

for year ending 31 December 19 **66**



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Figure 17. Hydrograph for Cabin Creek
near Seebe

for low flows; the straight line was extended and used to calculate the approximate base flow contribution to streamflow during flood stage (Fig. 18). The index wells selected for averaging the groundwater stage were those completed in the reservoir materials from which base flow was derived. There are no observation wells completed in the upper parts of the basin so these reservoir materials are not represented. The hydrographs of the index wells used (Fig. 19) are shown in Appendix A and Appendix B.

Total streamflow is calculated by computing the volume under the streamflow hydrograph (Fig. 13) during the budget period. Total streamflow for the period August 25, 1965 to August 25, 1966 was 20.56 inches of water over the basin area or 59 per cent of the total precipitation.

Evapotranspiration

Evapotranspiration includes water evaporated from the ground surface (streams, bogs, springs, seeps, and vegetation), from the soil-moisture zone, from the intermediate vadose zone, and from the water table, plus the moisture transpired by plants. Evapotranspiration is one component of the hydrologic budget which is difficult to measure directly.

Open-water evaporation is measured during the summer months with a standard Class A pan located in the confluence area at a site named Con. 5 (Plate IV).

A radiometer located at Con. 5 measures the net radiation. Data for net radiation were available for the months of June, July, and August, 1965. These data, along with corrected wind speed, mean air temperature, and mean dew-point temperature allowed the graphical solution of the modified Penman equation (Schulz, 1962) to obtain mean daily potential evapotranspiration in inches. The estimated potential evapotranspiration is compared with the corrected Class A pan evaporation (Table 4). The Class A pan data were corrected for convective heat losses through the sides and bottom of the pan (D. Storr, written communication).

AVE. WATER TABLE ELEVATION (FEET ABOVE M.S.L.) OF INDEX WELLS

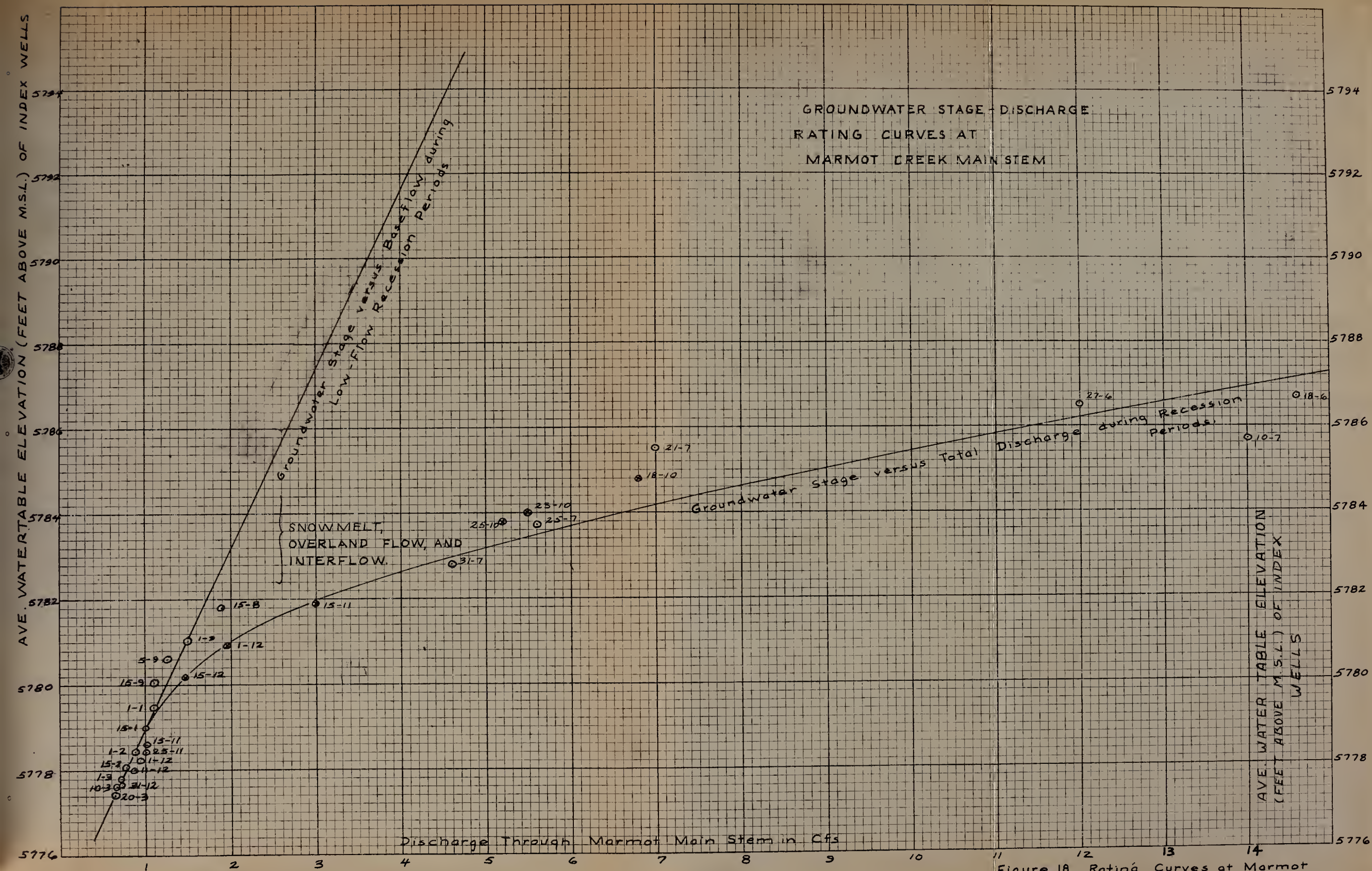


Figure 18. Rating Curves at Marmot Creek Main Stem

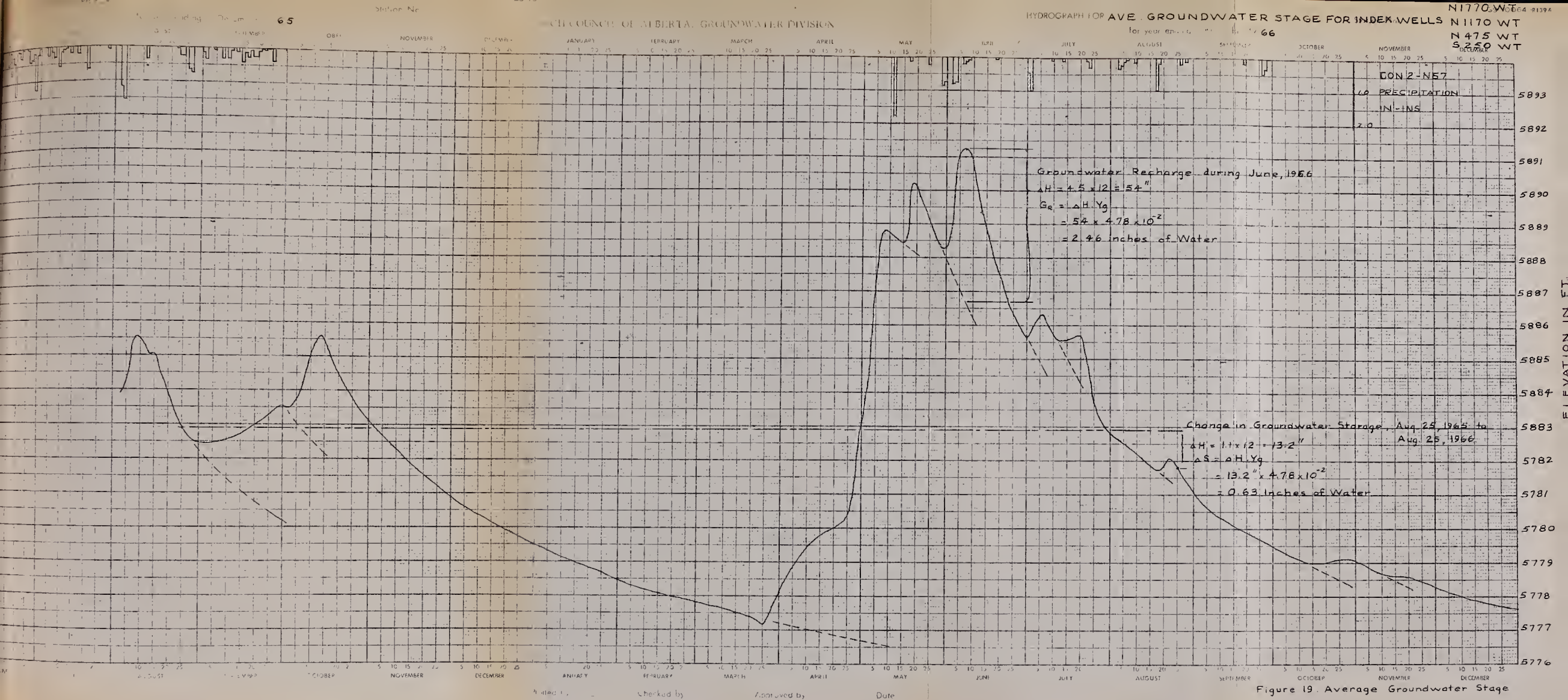


Table 4. Estimated Potential Evapotranspiration and Open-Water Evaporation for the months of June, July, and August, 1965 at Con.5, Marmot Creek Basin

Month Year Parameter	June 1965	July 1965	August 1965	Total evaporation inches water
Mean monthly air temperature (°F)	46	56	55	
Mean monthly dew point temperature (°F)	40	46	46	
Mean wind speed at 2 meters above surface (miles/day)	1.25	1.25	0.8	
Mean net solar radiation* (inches water/day)	0.20	0.28	0.18	
Mean air-drying capacity (inches water/day)	0.02	0.038	0.034	
Mean evaporation of a free water surface (inches water/day)	0.14	0.21	0.27	
Total estimated potential evapotranspiration (inches water)	4.2	6.51	5.74	16.41
Total corrected evaporation from Class A pan (inches water)	3.9	5.77	4.99	14.66

*The mean net solar radiation was obtained by converting the scalar values from the radiometer data to Langleys/Day.

1 Landley/Day = 0.667×10^{-3} inches water/day.

The total potential evapotranspiration, using the modified Penman method, is 16.41 inches for June, July, and August 1965. This value is 12 per cent higher than the corrected Class A pan evaporation for the same period. The evapotranspiration for the period August 25, 1965 to August 25, 1966 is solved for in the hydrologic equation as shown in Table 6. The evapotranspiration for the budget period is 14.82 inches or 43 per cent of the total precipitation. The evapotranspiration as calculated from the budget for a one year period is less than the potential evapotranspiration for the three preceding months as calculated from the modified Penman method.

Changes in Storage

An excess in precipitation over runoff and evapotranspiration results in an increase in water storage. Water can be stored on the surface, in the soil-moisture zone, in the intermediate vadose zone, and in the groundwater reservoir.

Changes in surface-water storage are confined mainly to the streams during late summer, but include changes in the water equivalent of snow pack during the rest of the year. No significant change in the amount of surface water storage was considered for the beginning and end of the budget period.

Changes in soil moisture and in intermediate vadose-zone moisture are measured directly by Coleman resistance units in the lower part of the basin; these units, however, have not been calibrated to date so that it is not possible to calculate storage in the various zones directly, using the Coleman data. Neutron scattering equipment has also been purchased and may eventually provide supplementary data for these zones; no neutron data are available at the present time.

Figure 20 shows resistivity variations for four selected sensors for the Coleman soil-moisture unit at Con. 2 (Map 6). Figure 21 shows variations in precipitation, maximum and minimum air temperatures, and soil temperatures at the same location. The soil temperatures were derived from the resistivities of the thermistors

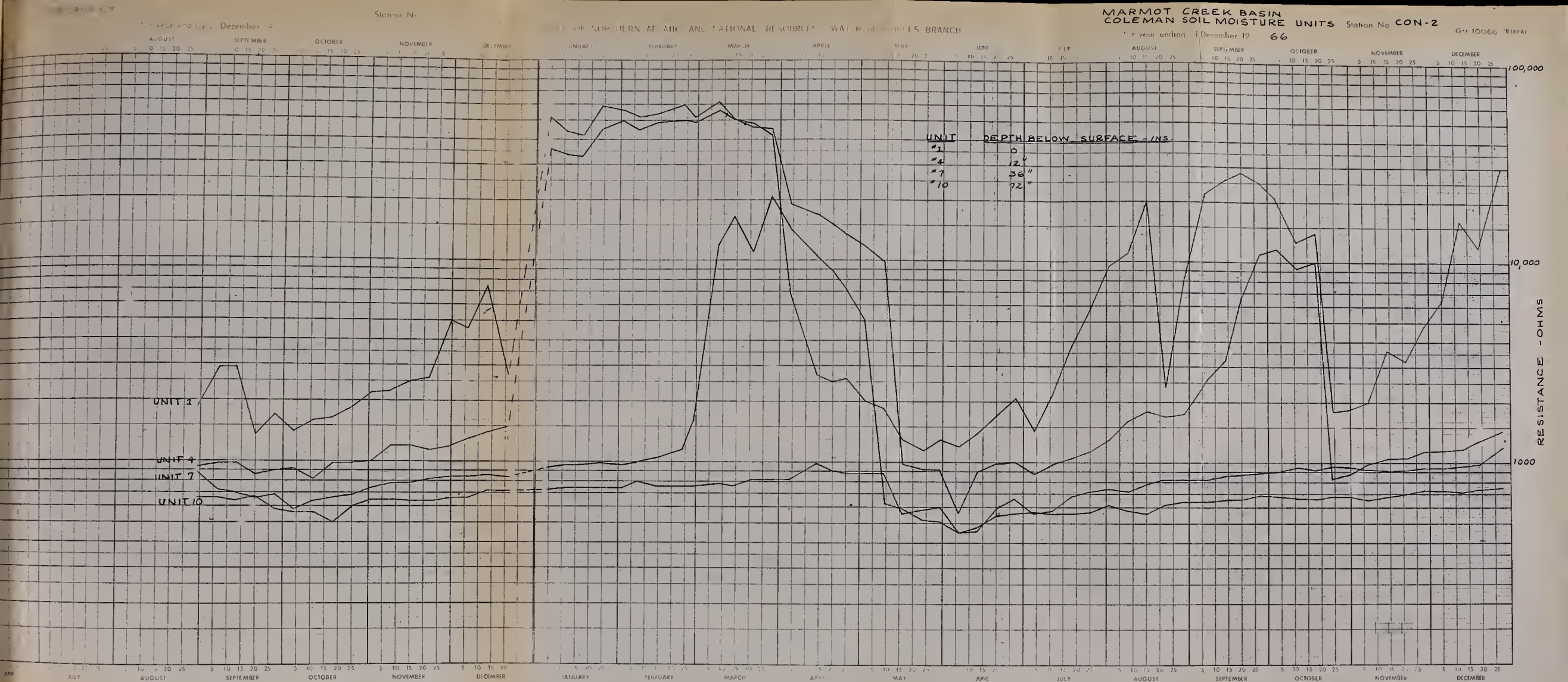


Figure 20. Resistivities for Coleman Soil

Moisture Units at Con2-N57

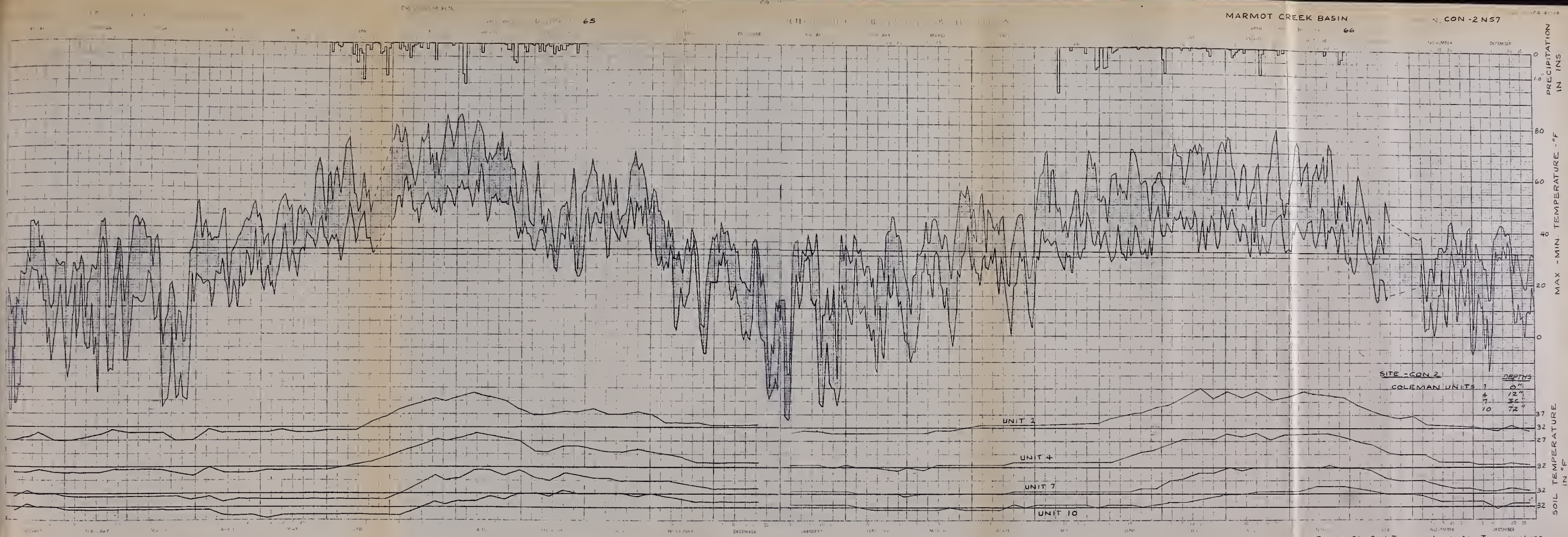


Figure 21. Soil Temperature, Air Temperature, and Precipitation at Con 2-N57

buried with the Coleman unit sensors. Figure 22 shows fluctuations in groundwater level approximately 200 feet south.

Significant groundwater recharge is noted on figure 22 starting on September 22, 1966 and continuing until October 3. Resistivities of the two shallow Coleman sensors remained high during this period, indicating the continued existence of a soil-moisture deficit at least to a depth of 1 foot.

During December 1965 the resistivities of the two shallow sensors greatly increased (Fig. 20). The most shallow thermistor indicates freezing conditions during January, February, and March. At the end of February the resistivity of Coleman sensor #7, located three feet below the surface, began to increase. At this same time the thermistor at the same depth indicated below freezing conditions. The increase in the resistivities of the Coleman units during the winter is interpreted to be the result of freezing conditions rather than the drying out of the soil.

The presence of frozen ground in the basin during the spring and early summer could severely retard groundwater recharge.

On August 25, 1966 the water table was within five feet of the surface and the most shallow Coleman sensor registered approximately 2,800 ohms. On August 25, 1965 this sensor was approaching the same value, indicating similar moisture conditions in the vadose zone at the beginning and end of the budget period. The mean groundwater stage declined one foot during the budget period. The corresponding change in groundwater storage is discussed in the section on the hydrologic budget.

Determination of Gravity Yield

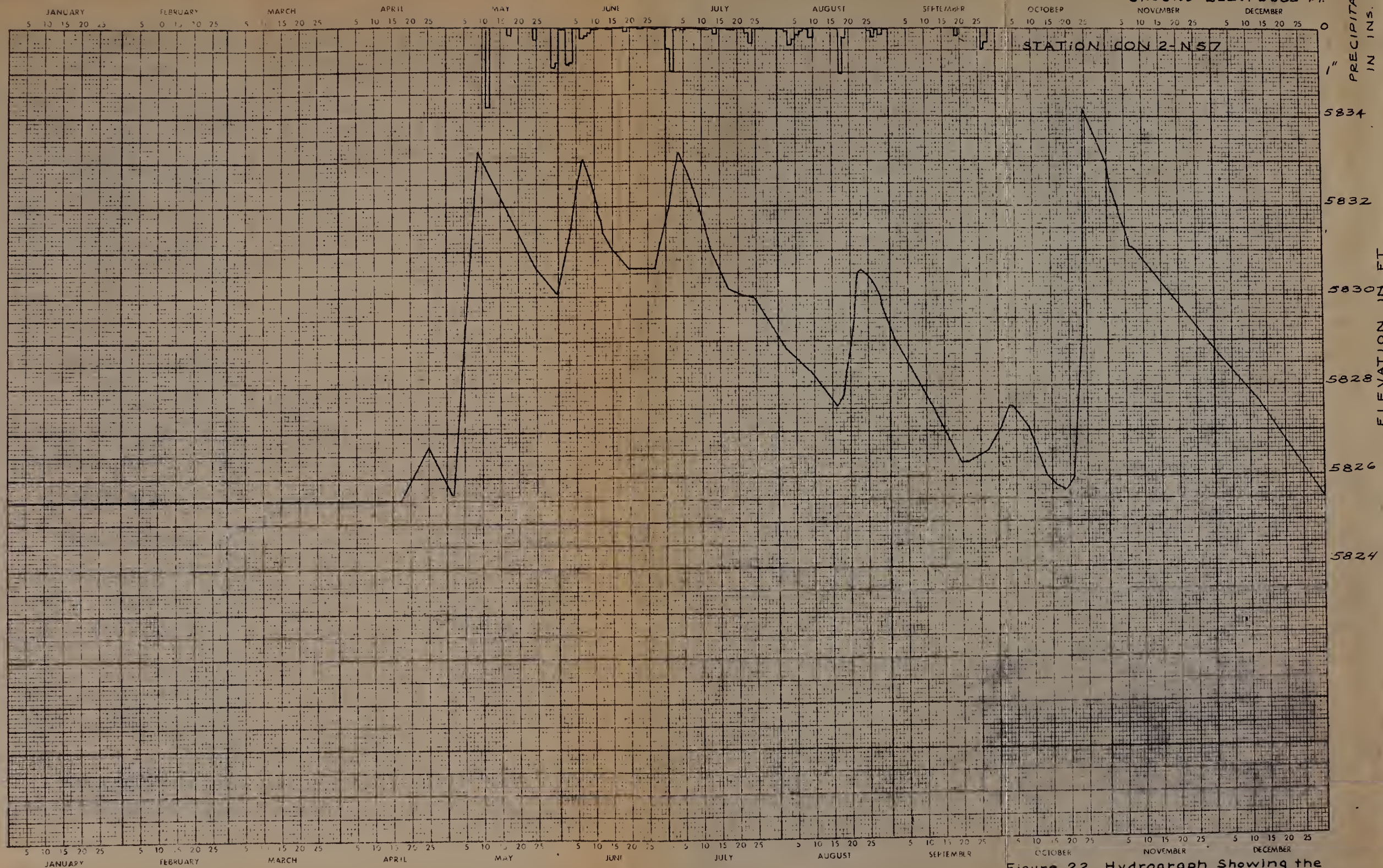
The approximate value of gravity yield* may be obtained by calculating the groundwater budget for periods when groundwater recharge and evapotranspiration losses from the water table are insignificant.

The period chosen was from January 1, 1966 to March 20, 1966 (Fig. 13).

*The gravity yield of a rock or soil after saturation or partial saturation is the ratio of the volume of water it will yield by gravity to its own volume during the period of groundwater recession. (Rasmussen and Andreasen, 1959)

for year ending 31 December 19 66

GROUND ELEV. 5835 FT.



Plotted by _____

Checked by _____

Approved by _____

Date _____

Figure 22. Hydrograph Showing the Response of Groundwater Stage to Precipitation Close to Con2-N57

The hydrograph of Marmot Creek Main Stem plotted on a logarithmic-time graph was a straight line for this period and streamflow consisted mainly of base flow.

Stating the groundwater equation:

$$G_R = R_g + ET_g + \Delta S_g \text{ (basin leakage is insignificant)} \quad (3)$$

The symbols G_R , R_g , ET_g and ΔS_g refer to groundwater recharge, base flow, evapotranspiration losses from the water table, and the change in groundwater storage, respectively.

For the period selected

$$G_R = 0$$

$$ET_g \approx 0$$

Rewriting equation (3):

$$R_g = -\Delta S_g. \text{ (} R_g = R \text{ for low streamflow recession periods)}$$

also $\Delta S_g = \Delta H \cdot Y_g$ where ΔH equals the change in the mean groundwater stage in inches (Fig. 19) and Y_g equals gravity yield.

$$\text{Therefore } R_g = -\Delta H \cdot Y_g \text{ or } Y_g = \frac{R_g}{-\Delta H} \text{ for the calculated intervals.}$$

The intervals began on January 1, 1966 for each calculation and extended over successively longer periods to assess any changes in gravity yield with time. From the calculations shown in Table 5 on p. 41 the gravity yield increased approximately 10 per cent over 3 months. This was probably due to more complete drainage of the deposits (Schicht and Walton, 1961), however, the increase was not conclusive so an average value was used. The average gravity yield equals 4.78×10^{-2} and is assumed to be the average gravity yield over the basin.

Calculation of the Hydrologic Budget

The hydrologic budget was calculated for the period August 25, 1965 to August 25, 1966, during which period the conditions given in the preceding sections were observed.

From equation (2):

$$P = R + ET + \Delta S, \text{ or } ET = P - R - \Delta S$$

The change in storage $\Delta S = \Delta S_g$, since ΔS_{sw} and ΔS_s are assumed = 0 at the beginning and end of the budget period. Also $\Delta S_g = \Delta H \cdot Y_g$. ΔH is the change in the mean groundwater stage for the budget interval from Figure 19, Y_g is calculated in Table 5, and R is measured from the hydrograph of Marmot Creek Main Stem. Precipitation is measured with the precipitation gauge network (Fig. 12), and the average precipitation over the basin (P) is calculated. Evapotranspiration (ET) is solved with the hydrologic equation (2) for the budget interval as shown in Table 6.

Table 5. Approximation of Gravity Yield

Measured interval (1966)	Period days	Total discharge* R in cfs-days	$R_g = R$ in inches of Water**	ΔH inches	$Y_g = R_g / -\Delta H$ ($\times 10^{-2}$)
Jan. 1-6	6	6.18	0.110	-2.64	4.17
Jan. 1-21	21	21.73	0.430	-10.20	4.21
Jan. 1-31	31	30.98	0.613	-12.36	4.96
Jan. 1-Feb. 9	40	38.56	0.763	-15.60	4.89
Jan. 1-Feb. 21	52	47.92	0.948	-18.36	5.16
Jan. 1-Mar. 13	85	63.55	1.258	-23.16	5.43
Jan. 1-Mar. 20	92	67.39	1.333	-25.20	5.28
					Average = 4.78×10^{-2}

*Discharge measured at Marmot Creek Main Stem

** Inches of water = cfs-day $\times \frac{1.98 \text{ Acre Feet}}{\text{cfs-day}} \times \frac{12 \text{ inches}}{\text{foot}} \times \frac{1}{1330 \text{ Acres}}^{***}$

*** Basin area contributing to flow during period of calculation.

Table 6. The Hydrologic Budget from August 25, 1965 to August 25, 1966.

$$ET = P - R - \Delta S, \quad \Delta S = \Delta S_g = \Delta H \cdot Y_g.$$

Budget Period	P-inches of water	R-inches of water	ΔH -inches	Y_g	ΔS_g -inches of water	ET-inches of water
August 25/65- August 25/66	34.75	20.56	-13.2	4.78×10^{-2}	-0.63	14.82
Percentage of total precipitation	100	59				43

GROUNDWATER BUDGET

Part of the rainfall and snowmelt percolates down through the soil to the water table. The groundwater reservoir is recharged, resulting in a rise of the water table and an increase in groundwater storage. Some groundwater drains into the streams as base flow and some is lost by evapotranspiration.

From equation (3):

$$G_R = R_g + ET_g + \Delta S_g \text{ (symbols previous defined).}$$

Components of the Groundwater Budget

Groundwater Recharge

The water table rises in response to rainfall. Groundwater drains into the stream and, when there is no recharge, a continued recession in the groundwater hydrograph results (Rasmussen and Andreassen, 1959). The dashed lines shown in Figure 19 represent the projected recessions of the mean groundwater stage under conditions of no recharge. The difference between peak stage after recharge and the projection of the recession curve under the peak, multiplied by the gravity yield, is equal to the total recharge for that interval. The recharge for the year is the sum of the recharge for all intervals as taken from the mean groundwater hydrograph multiplied by the gravity yield. Monthly recharge calculations for the period August 25, 1965 to August 25, 1966 are shown in Table 7. There was a recharge of 15.09 inches of water (43 per cent of the precipitation) to the groundwater reservoir during the budget period.

Groundwater Runoff

Groundwater runoff or base flow is calculated for each month from the hydrograph of base flow (Fig. 13) by summing the area under the base-flow curve for monthly periods. These values in cfs-days are converted to inches of water over the basin area and are given in Table 7.

Base flow made up 6.91 inches of water or 34 per cent of the total streamflow for the budget period (Table 7).

Groundwater Storage

The difference in groundwater stage, ΔH in inches, for the beginning and end of the month, times the ratio of the reservoir area to the basin area, multiplied by the gravity yield Y_g , equals the net change in groundwater storage in inches over the basin during that month. ΔH is read directly from the hydrograph, whereas the area of the basin contributing to baseflow is measured from the base map with a planimeter. Gravity yield is taken from Table 5. The change in storage for each month during the budget period is shown in Table 7. There was a net loss in groundwater storage of 0.63 inches of water for the budget period.

Groundwater Evapotranspiration

Water is lost from the upper surface of the groundwater reservoir by evaporation from the soil and by transpiration through plants. Where the water table approaches the land surface, as in the groundwater seepage areas (Map 3), large amounts of groundwater may be lost to evapotranspiration.

The loss of groundwater to evapotranspiration can be calculated by balancing the groundwater budget. Rewriting equation (3):

$$ET_g = G_R - R_g - \Delta S_g$$

Monthly amounts of groundwater loss to evapotranspiration were calculated for the period August 25, 1965 to August 25, 1966 and are shown in Table 7. From Table 6 the total evapotranspiration for the budget period = 14.82 inches. From Table 7 the evapotranspiration from groundwater = 9.00 inches. Remainder = 5.82 inches. The remaining 5.82 inches of evapotranspiration are supplied from the vadose zone (includes the soil moisture zone). During the budget period the groundwater reservoir supplied 61 per cent of the total evapotranspiration.

Calculations of the Groundwater Budget

The components of the groundwater budget were calculated by the methods given in the previous sections and by solving the budget equation $ET_g = G_R - R_g - \Delta S_g$

for each month during the budget period. These calculations are shown in Table 7.

Table 7: Groundwater Budget from August 25, 1965 to August 25, 1966.

Year/ Month	Ratio of Basin Area Contributing to Base Flow in Acres/Basin Area in acres	R-Inches of water	R_g Inches of water	G_R Inches of water	ΔS_g Inches of water	ET_g Inches of water
1965						
August(25-31)	2282/2282	0.28	0.12	0.12	-0.23	+0.23
Sept.	2282/2282	1.61	0.60	1.66	+0.57	+0.49
Oct.	2035/2282	2.29	0.74	0.38	-0.21	+0.85
Nov.	2035/2282	0.98	0.53	0	-1.15	+0.62
Dec.	2035/2282	0.48	0.40	0	-0.73	+0.33
1966						
Jan.	1330/2282	0.32	0.32	0	-0.33	+0.01
Feb.	1330/2282	0.22	0.23	0	-0.23	0
Mar. (1-25)	1330/2282	0.17	0.16	0	-0.15	-0.01
Mar. (26-31)	1790/2282	0.08	0.05	0.36	+0.32	-0.01
April	1790/2282	0.36	0.37	2.46	+2.26	-0.17
May	2282/2282	3.28	1.09	4.70	+2.98	+0.63
June	2282/2282	6.18	1.07	2.46	-1.49	+2.88
July	2282/2282	3.36	0.79	1.61	-1.66	+2.48
August (1-25)	2282/2282	0.95	0.44	0.34	-0.58	+0.48
Total in inches of Water		20.56	6.91	15.09	-0.63	9.00
Per Cent of Precipitation (when P = 34.75 ins.)	59	20	43			26
Per Cent of Streamflow	100	34				

SURFACE WATER QUALITY AND GROUNDWATER QUALITY

Figure 23 shows the creek waters of Marmot Creek basin to vary from moderately hard during peak streamflow or low percentage base-flow periods to hard during low streamflow or high percentage base-flow periods (Fig. 23). Stream water from the cirque remains moderately soft throughout the sampling period, whereas stream water from Cabin Creek remains hard. Variation in hardness is caused by the variation in concentration of calcium and magnesium carbonates in solution because non-carbonate hardness remains almost unchanged.

The stream water chemical patterns (Fig. 24) show that calcium and magnesium bicarbonates are the main chemical constituents of the stream water. The sulfate anion concentration is low, and the alkali (Na+K) and the chloride anion concentrations negligible. Other cations are almost absent (Table 8).

The calcium and magnesium bicarbonate concentration in the water at the Middle Fork weir is about 40 per cent higher than at the cirque station. This increase is probably caused by the higher carbonate content of the surficial materials below the cirque than above the cirque.

The pattern diagrams for Twin Creek are very similar to those for Middle Fork Creek during both high and low flow periods, suggesting that the alpine contributions to streamflow in each case are comparable. The Cabin Creek waters are more highly mineralized than those for either Twin or Middle Fork Creeks (Fig. 24) with only a small degree of dilution during peak flow periods. This may be caused by a larger base-flow contribution to streamflow within the Cabin Creek sub-basin reflecting the larger percentage of the basin lying below the subalpine zone. The mineral content of the waters collected at Marmot Creek Main Stem appears to be the average of the three tributary streams.

Turbidity is not appreciable even after a heavy rainfall (Table 8). The sediment analyses at Marmot Creek Main Stem show a maximum of 87 ppm after heavy summer rains and an average about 3 ppm during the open-water season (D. Davis,

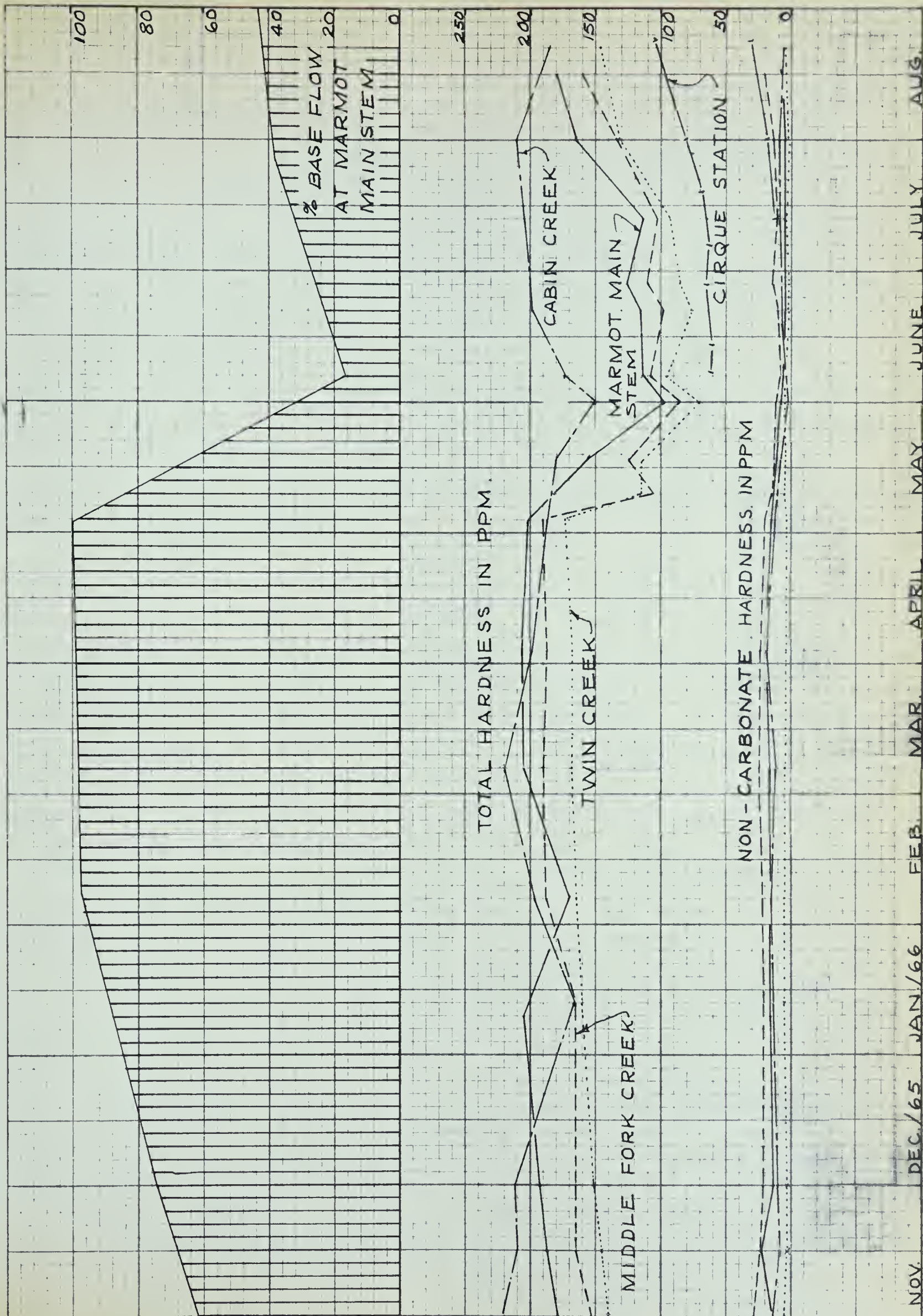


Figure 23. Relation Between Mineral Content of the Streams of Marmot Creek Basin and Baseflow at Marmot Main Stem

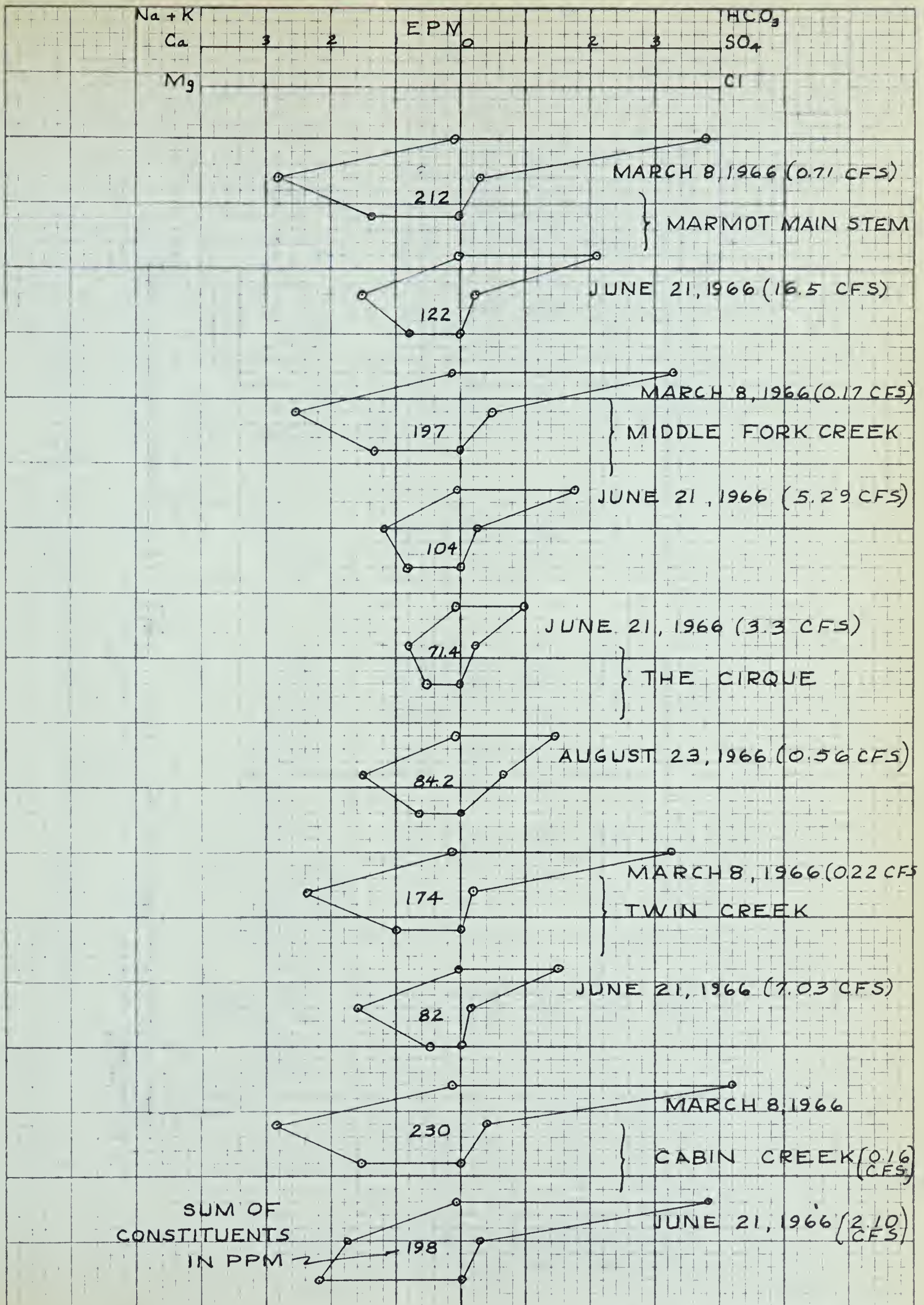


Figure 24. Pattern Diagrams Showing the Chemical Types of Creek Waters in the Marmot Creek Basin

Table 8. Chemical analyses of stream waters from the Marmot Creek basin

Date of collection	pH	Turbidity - ppm	Specific conductance x 10 ⁶ at 25°C	PARTS PER MILLION			EQUIVALENTS PER MILLION										
				Iron Fe	Hardness as CaCO ₃		Sum of constituents	SO ₄	Cl	HCO ₃	NO ₃	Ca	Mg	Na + K	Na P/C		
					Non carbon-	Total											
MARMOT MAIN STEM																	
8/3/66	8.3	0.5	374		14	205	212	0.374		3.821	0.014	2.745	1.348	0.087	2.082		
21/6/66	7.9	0.4	203		6	116	122	0.208		2.198		1.532	0.789	0.044	1.840		
CABIN CREEK																	
8/3/66	8.1	0	407		12	221	230	0.395		4.182		2.864	1.554	0.131	2.869		
21/6/66	8.1	0.1	362		8	199	198	0.270		3.821		1.776	2.203	0.087	2.139		
TWIN CREEK																	
8/3/66	7.8	0	318		4	168	174	0.187		3.280		2.370	0.986	0.087	2.526		
21/6/66	7.7	1	150		3.5	76.9	82.3	0.125		1.476		1.073	0.460	0.044	2.759		
MIDDLE FORK CREEK																	
8/3/66	8.1	0	353	0.02	23	188	200	0.499		3.313	0.005	2.485	1.307	0.087	2.243		
21/6/66	7.8	0.5	191		14	110	114	0.250		1.755		1.193	0.789	0.044	2.148		
CIRQUE STATION																	
27/6/66	7.4	1	132		9.1	63.8	71.4	0.229		1.017	0.005	0.798	0.477	0.044	3.299		
23/8/66	7.9	0.4	207		32	105	116	0.291	0.085	1.099	0.056	0.938	0.444	0.131	8.628		

personal communication).

In general, the groundwaters are higher in dissolved salts than the surface waters but are similar in type (Figs. 25 and 26). Some groundwater samples contain appreciable amounts of iron (Table 9), probably the result of the well-completion methods carried out at these sites.

The pattern diagram for the piezometer at S835P (developed in Fernie Shale) is somewhat different than the diagrams for more shallow groundwaters since the concentrations of sulfate and the alkali metals are appreciable, while the magnesium cation concentration is low. Hardness, in this case, is mainly calcium carbonate. The pattern diagrams for this piezometer and for the piezometers M300P and S265P are based on a single analysis and do not support definite conclusions, however, the differences in pattern from those of other groundwaters suggest further investigations are required.

The total hardness of the groundwater at site S400WT increases with depth to the water table, indicating dilution during recharge periods (Fig. 27). The changes in the sulfate-chloride and the calcium-magnesium ratios may also be caused by dilution.

In summation, both surface waters and groundwaters appear to be mainly of calcium-magnesium bicarbonate type and seem to become more mineralized at low stages. These similarities in pattern and the bicarbonate nature of the groundwater all support the unconfined-flow hypothesis which postulates groundwater recharge being derived mainly from precipitation and stream base flow draining directly from the groundwater reservoir.

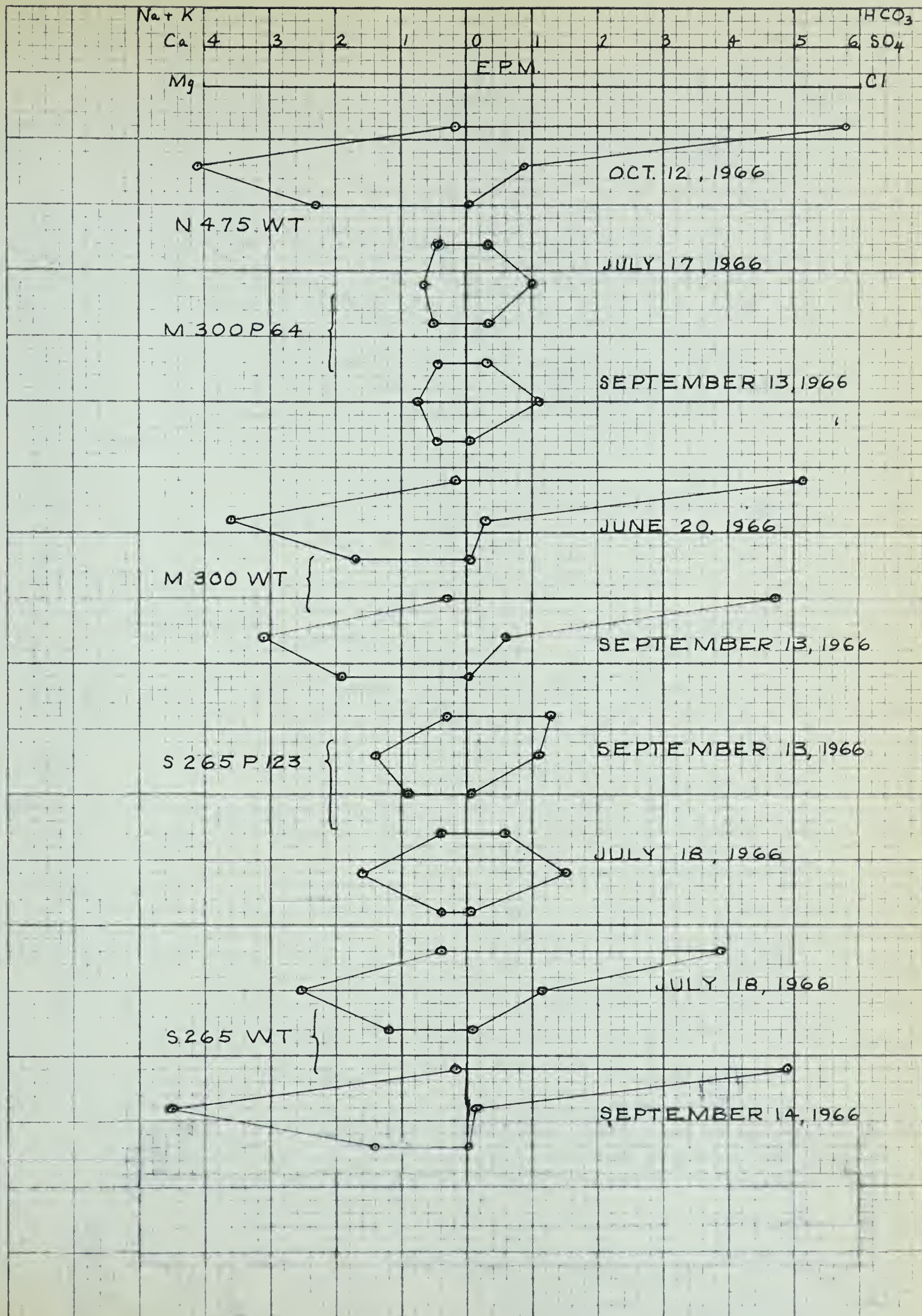


Figure 25. Pattern Diagram Showing the Chemical Types of Groundwater in the Marmot Creek Basin

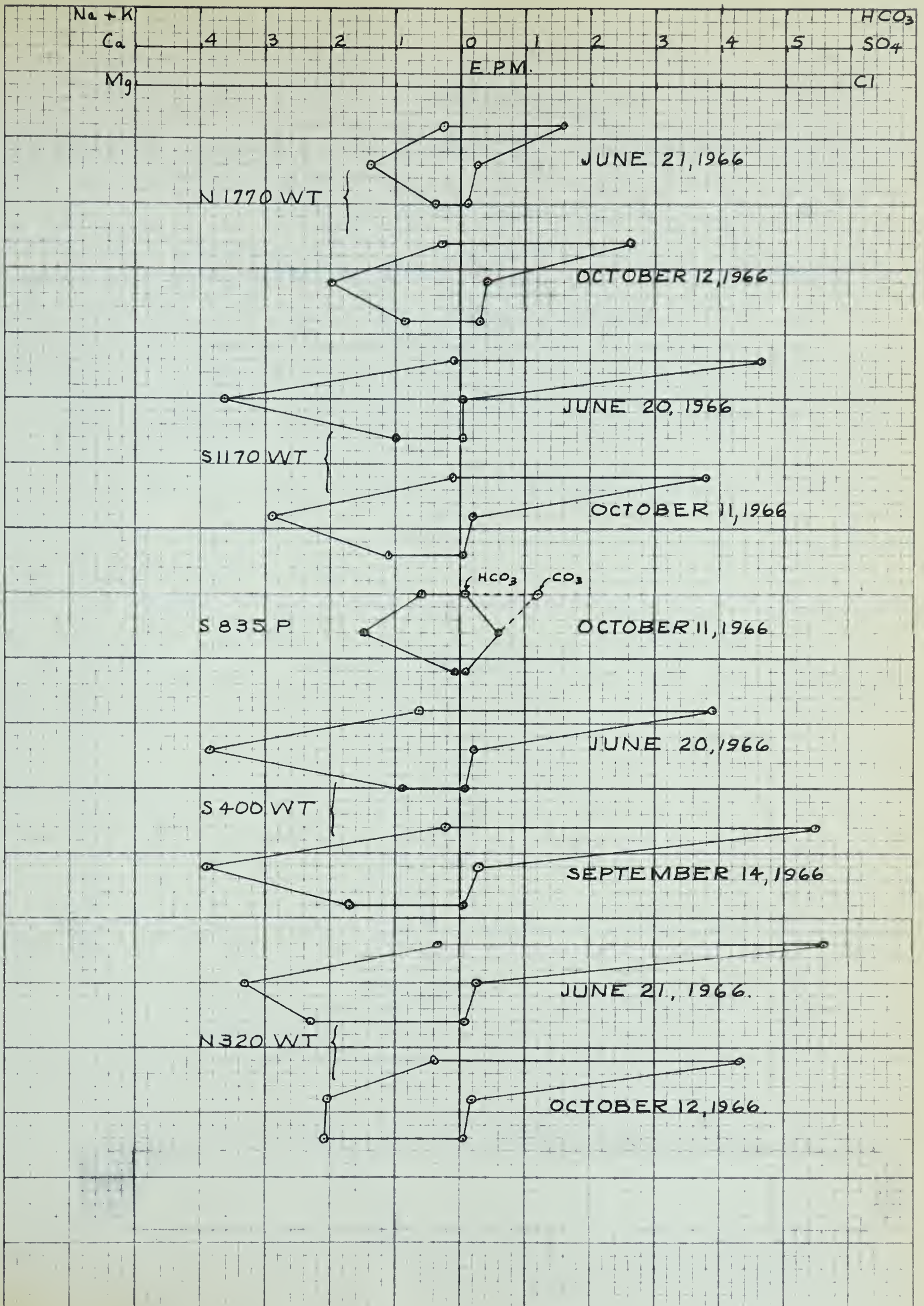


Figure 26. Pattern Diagrams Showing the Chemical Types of Groundwater in the Marmot Creek Basin

MARMOT CREEK BASIN

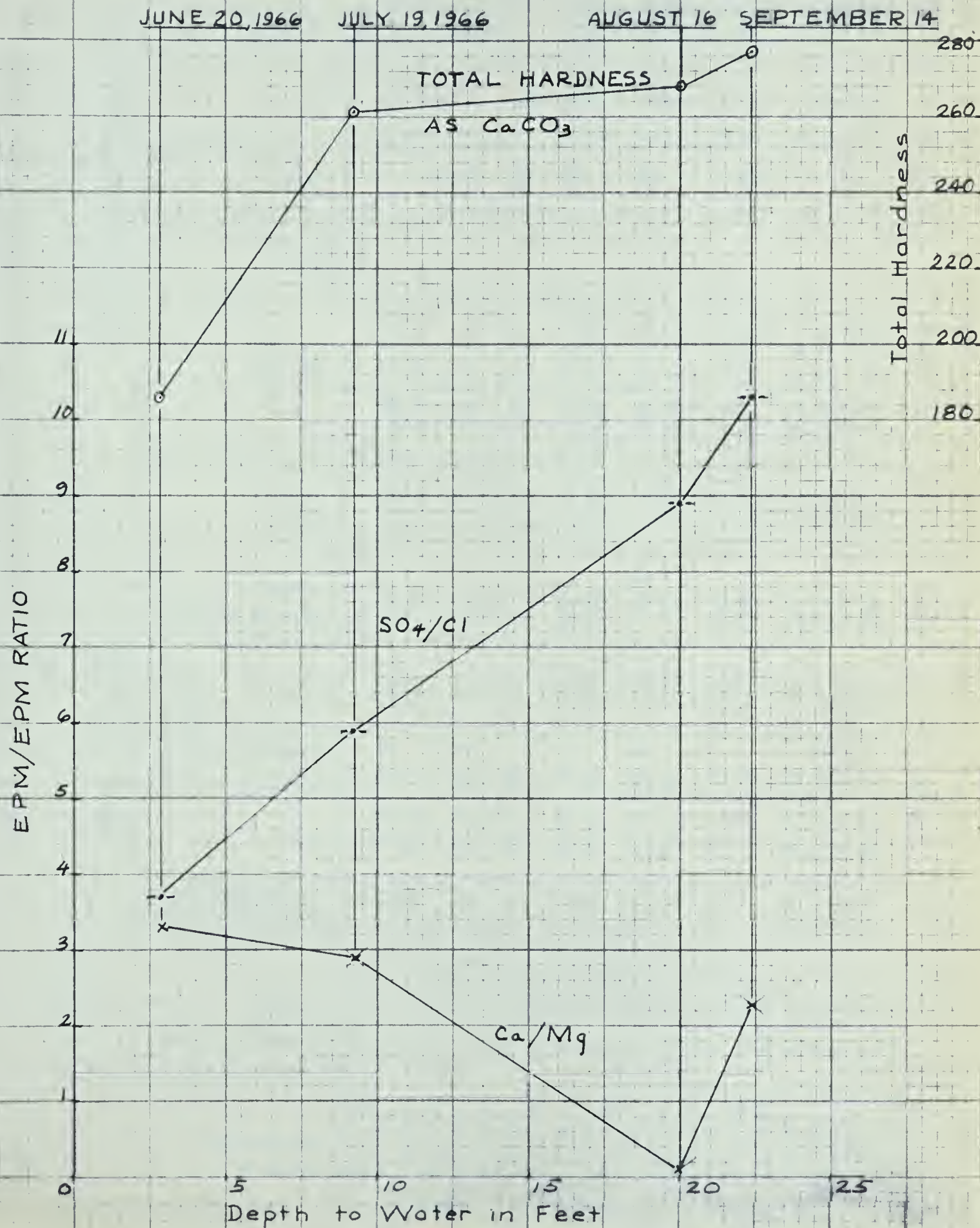


Figure 27. The Change in Groundwater Quality versus Depth to Water at Site S400 WT

Table 9. Chemical analyses of groundwaters from the Marmot Creek basin

Date of collection	Depth to water (feet)	pH	Specific conductance $\times 10^6$ at 25°C	PARTS PER MILLION			EQUIVALENTS PER MILLION									
				Iron	Hardness as CaCO_3		Sum of constituents	SO_4	Cl	HCO_3	CO_3	NO_3	Ca	Mg	Na + K	Na P/C
					Non-carbonate	Total										
WELL NO. S265 WT																
18/7/66	16.1	7.7	370	6.0	0.0	188	204	0.166	0.028	3.870			2.545	1.208	0.348	8.485
14/9/66	17.9	7.7	444	22.6	1	246	250	0.146	0.012	4.904			3.498	1.414	0.174	3.421
WELL NO. S265 PRM123																
18/7/66	47.9	6.9	238	21.0	72.5	100	135	1.477	0.056	0.558		0.024	1.587	0.411	0.261	11.555
WELL NO. S265 RM123																
13/9/66	49.0	7.2	248	16.7	49	113	137	1.102	0.028	1.279		0.002	1.362	0.896	0.261	10.360
WELL NO. M300 WT																
18/7/66	9.2	7.5	470	35.0	5	249	262	0.374	0.028	4.871		0.002	3.248	1.726	0.261	4.985
13/9/66	9.1	7.5	459	10.9	18	254	266	0.562	0.028	4.674			3.119	1.915	0.305	5.704
WELL NO. M300 P-RM64																
18/7/66	14.0	8.3	165	57.0	39.6	56.1	90.0	0.998	0.028	0.328		0.032	0.624	0.493	0.435	28.029
13/9/66	15.1	7.4	161	16.2	42	57.7	93	1.082	0.028	0.312			0.729	0.419	0.435	27.484
WELL NO. N320 WT																
21/6/66	5.6	7.8	524	19.2	0	281	308	0.229	0.056	5.625			3.318	2.293	0.348	5.839
12/10/66	6.4	8.0		3.2	0	205	220	0.187	0.028	4.280		0.002	2.001	2.096	0.392	8.722
WELL NO. S400 WT																
20/6/66	2.8	7.7	382	38.0	0	186	221	0.208	0.056	3.920			2.844	0.871	0.609	14.082
19/7/66	9.2	7.7	486	51.0	0.0	261	276	0.166	0.028	5.297			3.892	1.323	0.261	4.766
16/8/66	20.0	7.9	502	10.0	0.0	268	294	0.250	0.028	5.412		0.003	0.115	1.249	0.218	13.751
14/9/66	22.3	7.7	498	30.0	2	277	289	0.291	0.028	5.494			3.872	1.660	0.218	33.728
WELL NO. N475 WT																
12/10/66	18.9	7.6		1.0	29	319	339	0.853	0.028	5.806		0.002	4.067	2.302	0.174	2.660

Table 9. (Continued)

Date of collection	Depth to water (feet)	pH	Specific conductance $\times 10^6$ at 25°C.	PARTS PER MILLION				EQUIVALENTS PER MILLION								
				Iron	Hardness as CaCO ₃		Sum of constituents	SO ₄	Cl	HCO ₃	CO ₃	NO ₃	Ca	Mg	Na + K	Na P/C
					Non carbonate	Total										
WELL NO. S835P 12/10/66	24	9.9		1.0	10.3	78	113	0.562	0.056	0.066	1.132	0.002	1.477	0.107	0.609	28.156
WELL NO. S1170 WT 20/6/66	23.8	7.9	419	0.36	0	230	234	0.042	0.028	4.641			3.613	0.978	0.087	1.860
12/10/66	41.7	7.4		2.2	10	199	206	0.208	0.028	3.772		0.002	2.859	1.118	0.131	3.177
WELL NO. N1770 WT 21/6/66	14.1	7.6	185	1.26	9.3	89.1	108	0.250	0.113	1.591			1.387	0.395	0.261	12.777
12/10/66	29.2	8.2		1.4	9	141	161	0.416	0.028	2.640			1.971	0.847	0.261	8.478

EVALUATION OF RESULTS AND RECOMMENDATIONS FOR FUTURE WORK

The groundwater budget for the Marmot Creek basin was based on the assumption that the moisture content of the soil-moisture and intermediate vadose zones was the same at the beginning and at the end of the budget interval. This validity of assumption could and should be tested by combining groundwater and vadose-water instrumentation at future instrumentation sites.

The fluctuations of groundwater stage were assumed to represent the rise and fall of the unconfined water table. During the spring and early summer, however, when the ground is still partially frozen, parts of the groundwater reservoir may actually be confined by ice, and the rising water levels recorded in the observation wells may not represent the true recharge to the groundwater reservoir. The combining of thermistor units with water-table observation-well installations will show the intervals during which the ground is frozen and help to resolve this problem.

Actual evapotranspiration was calculated from the hydrologic equation by subtracting streamflow and change in storage from the total measured precipitation for the budget period. Streamflow which is 59 per cent of the measured precipitation is measured at the main discharge station; the measured flow is estimated to be within two per cent of the actual flow (D. Davis, written communication). The change in storage at the start and end of the budget period is less than two per cent of the measured precipitation, therefore, a large error in the measurement of change in storage would not seriously effect the calculated evapotranspiration. However, in a complex watershed the measured annual precipitation may differ from the actual annual precipitation by as much as 20 per cent and the total evapotranspiration calculated therefrom will have the same degree of error. The gravity yield is equal to the ratio of the volume of water discharged from the groundwater reservoir to the volume of reservoir dewatered. Considerable error may exist in the estimation of the volume of reservoir dewatered as no observation wells are located in the upper half of the basin. The main discharge station measures the volume of water discharged from the ground-

water reservoir to the stream during low flow recession periods. However, if part of this groundwater discharge is stored on or below the ground surface as ice during the period of calculation, then the discharge station would be measuring less than the total groundwater discharge and the calculated value for gravity yield would be less than the true value. These combined errors could result in 100 per cent error in the calculation of evapotranspiration losses from the groundwater reservoir if all the errors were accumulative. When one considers the high infiltration rate and the high water table over much of the basin area it seems logical that groundwater flow should supply the estimated 61 per cent of the total evapotranspiration losses.

Groundwater instrumentation and research in the Marmot Creek basin are well on the way but are still far from completion. In addition to the correlation of surface-moisture, soil-temperature, and groundwater instrumentation mentioned immediately above, future work should include: (1) additional groundwater instrumentation at the sub-basin outlets for the measurement of underflow, (2) testing for fracture permeability in jointed Spray River siltstone and for gravity yields of reservoir materials, (3) field measurement of hydraulic conductivity for the Fernie and Kootenay Shale members, (4) evaluation of a network of small-diameter (1/2 inch) piezometers installed with portable equipment in 1966 and possible extension of this network, and (5) further assessment of chemical changes in groundwater as influenced by position in the flow systems.

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APPENDIX A

Hydrographs of Groundwater Instrumentation in Marmot Creek Basin, 1965

2. *Myrica*

Myrica (L.) Rostk. & Schmidt. *Myrica* (L.) Rostk. & Schmidt.

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Myrica (L.) Rostk. & Schmidt. *Myrica* (L.) Rostk. & Schmidt.

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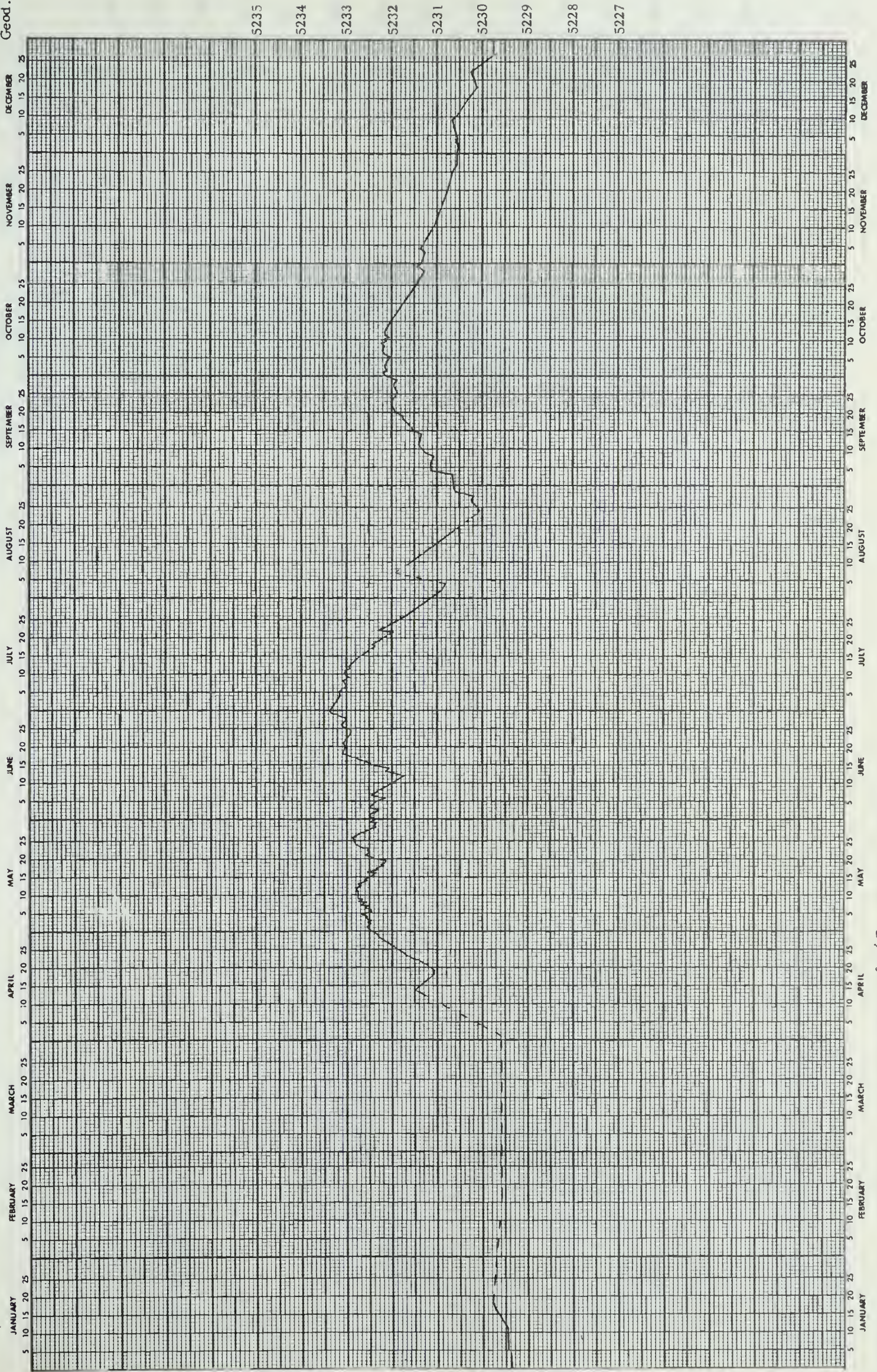
Myrica (L.) Rostk. & Schmidt. *Myrica* (L.) Rostk. & Schmidt.

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. 235 WT-RM28

for year ending 31 December 19 65

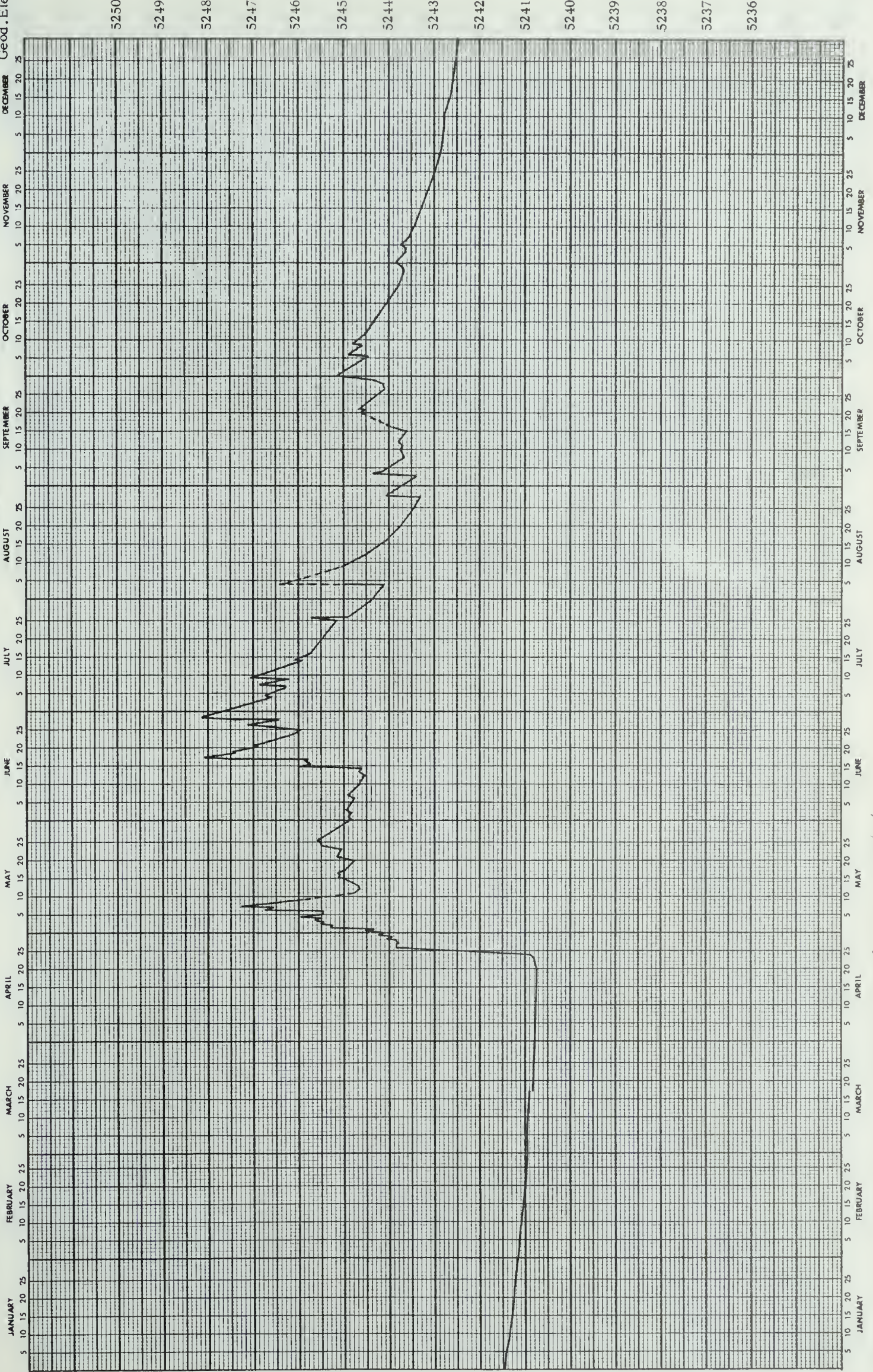
Mean
Geod. Elev.



for year ending 31 December 19 65

Mean

Geod. Elev.



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11-42

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. S265 WT/RM40

for year ending 31 December 19 65

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

Mean
Geod. Elev.

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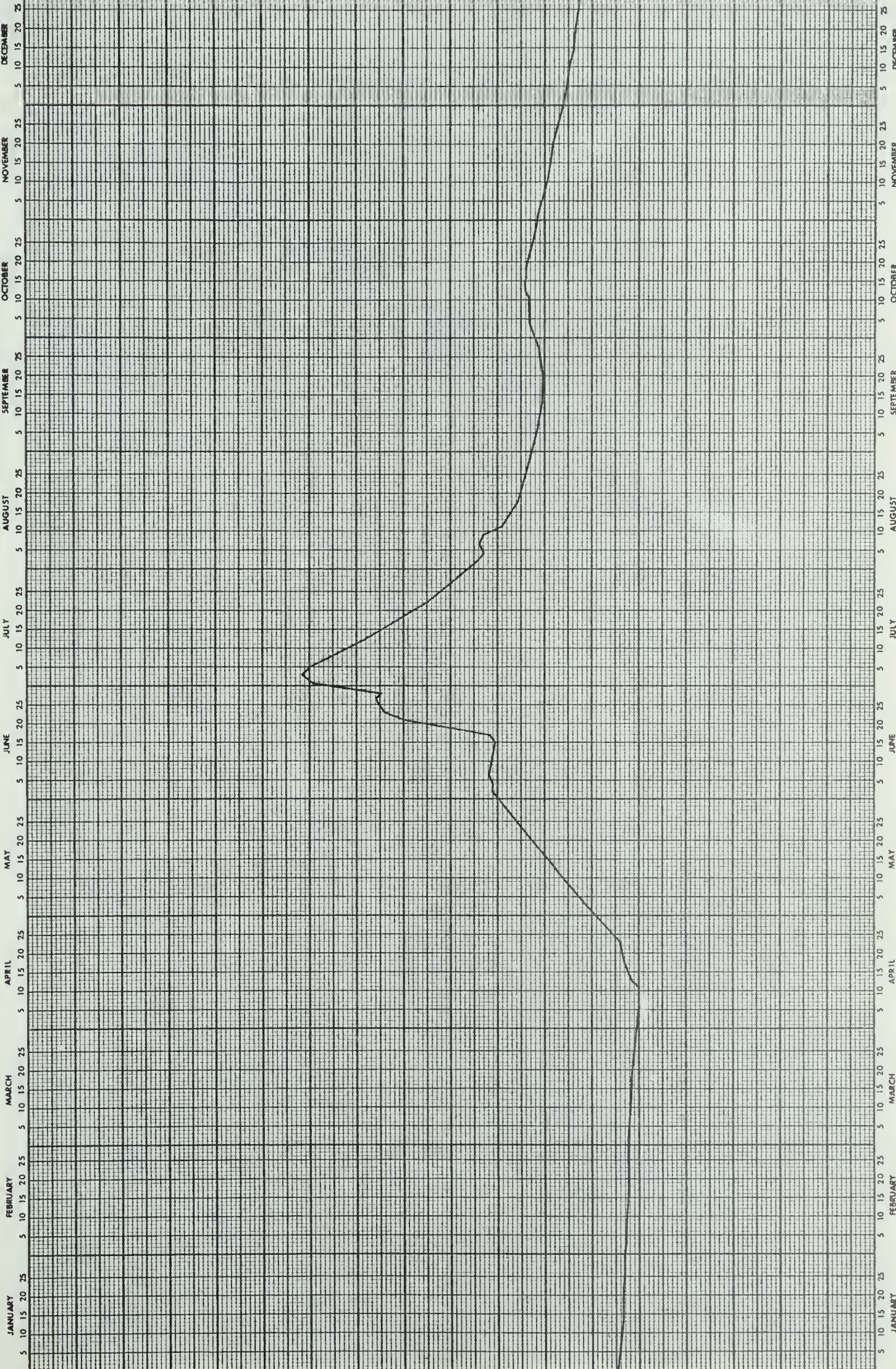
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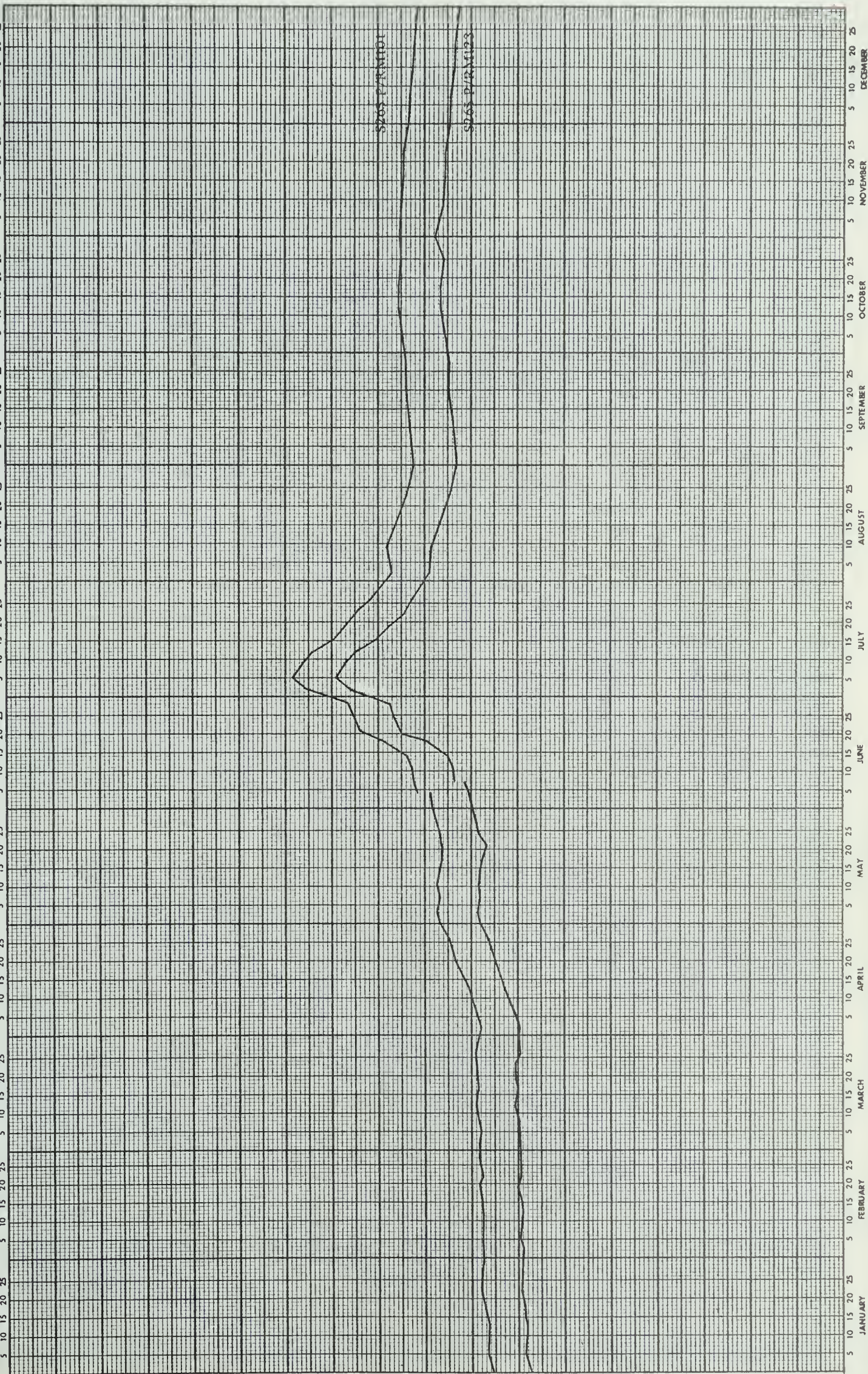
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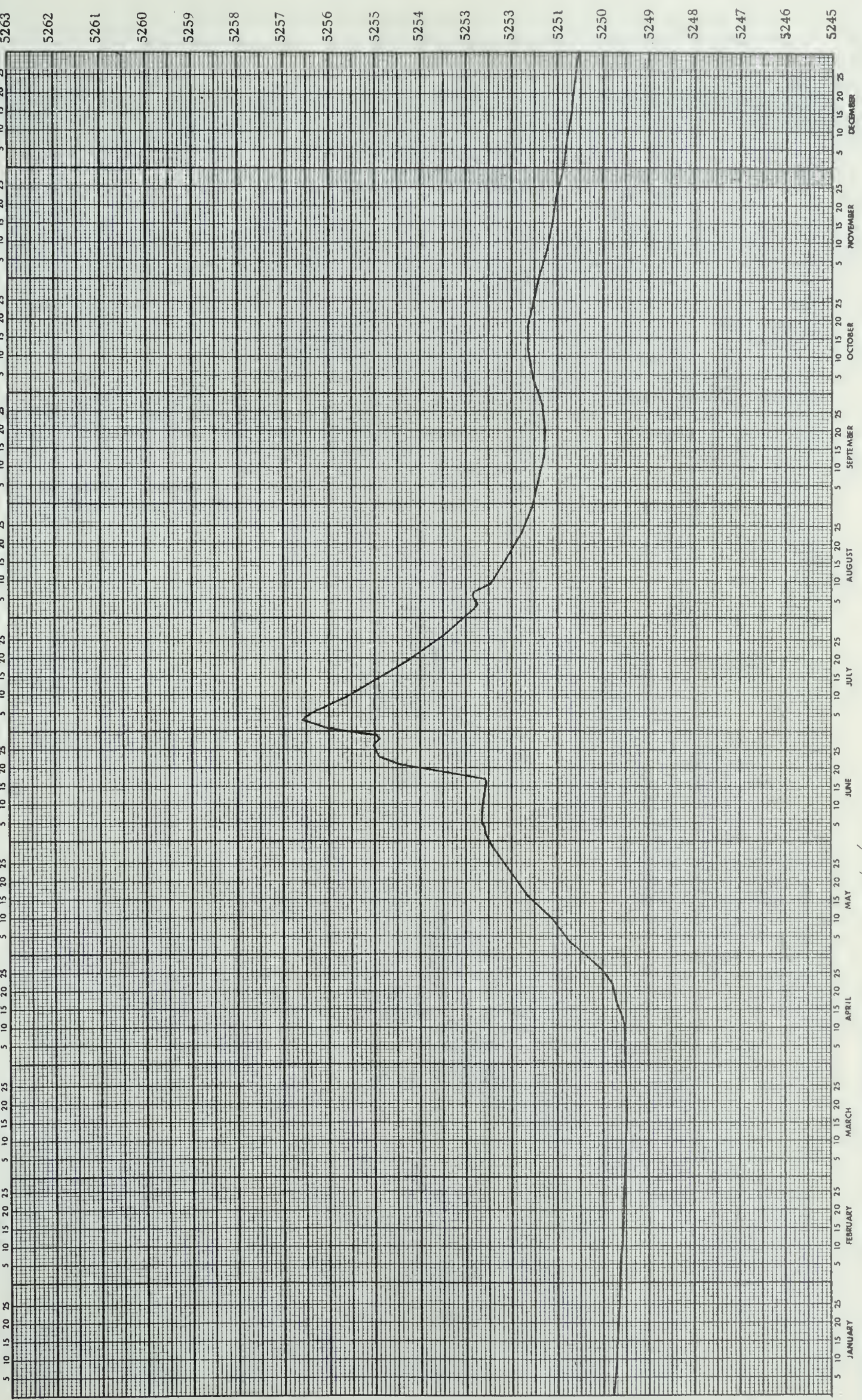
Plotted by _____ Checked by _____ Approved by *WRS* Date 8/2/66

Mean
Geod. Elev.



for year ending 31 December 19 65

Mean Geod. Elev. 5263



RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

HYDROGRAPH FOR

MARMOT CREEK BASIN Water-table well

Station No.

M300 WT/RM16

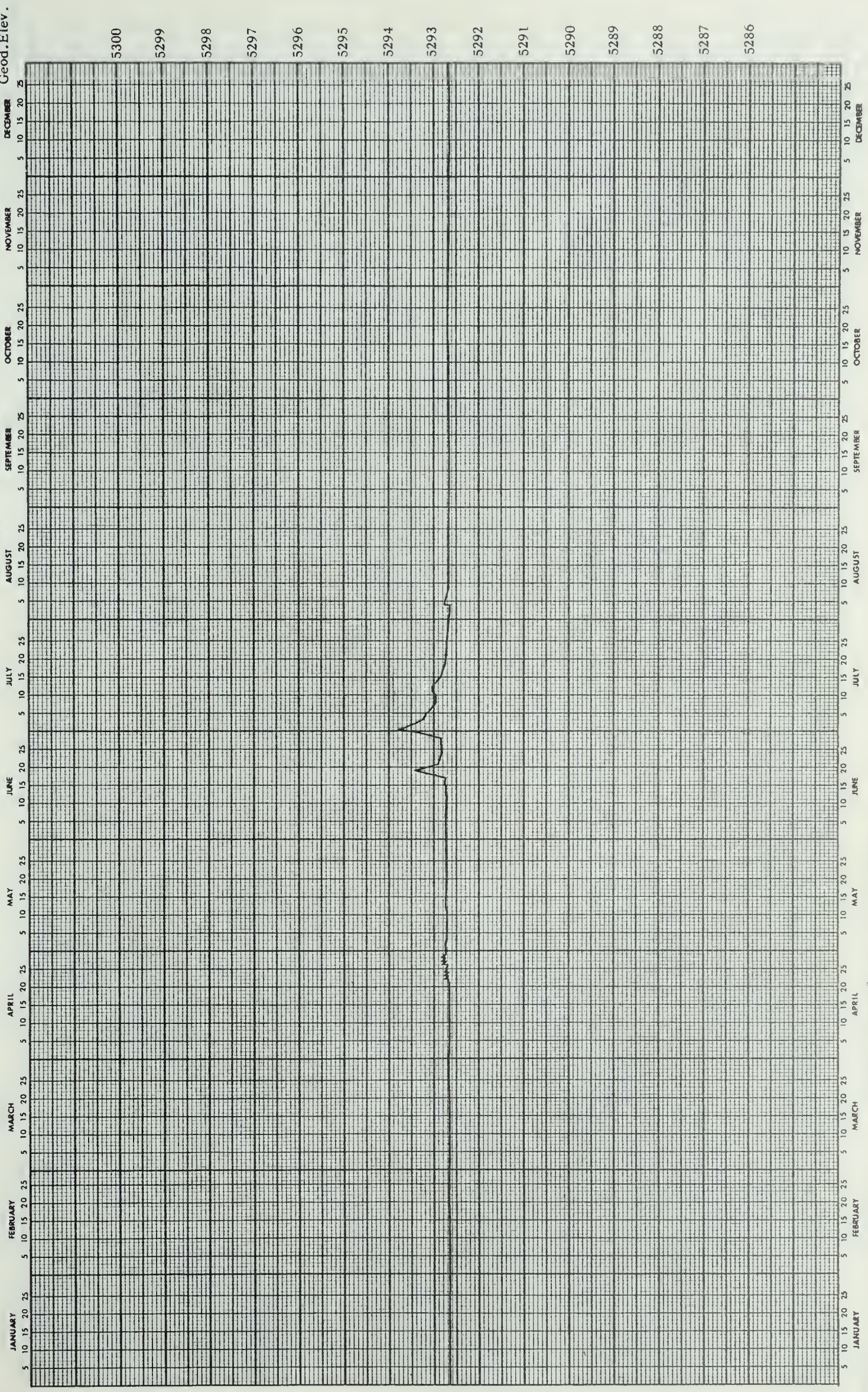
R 139A

n=22

Mean

Geod. Elev.

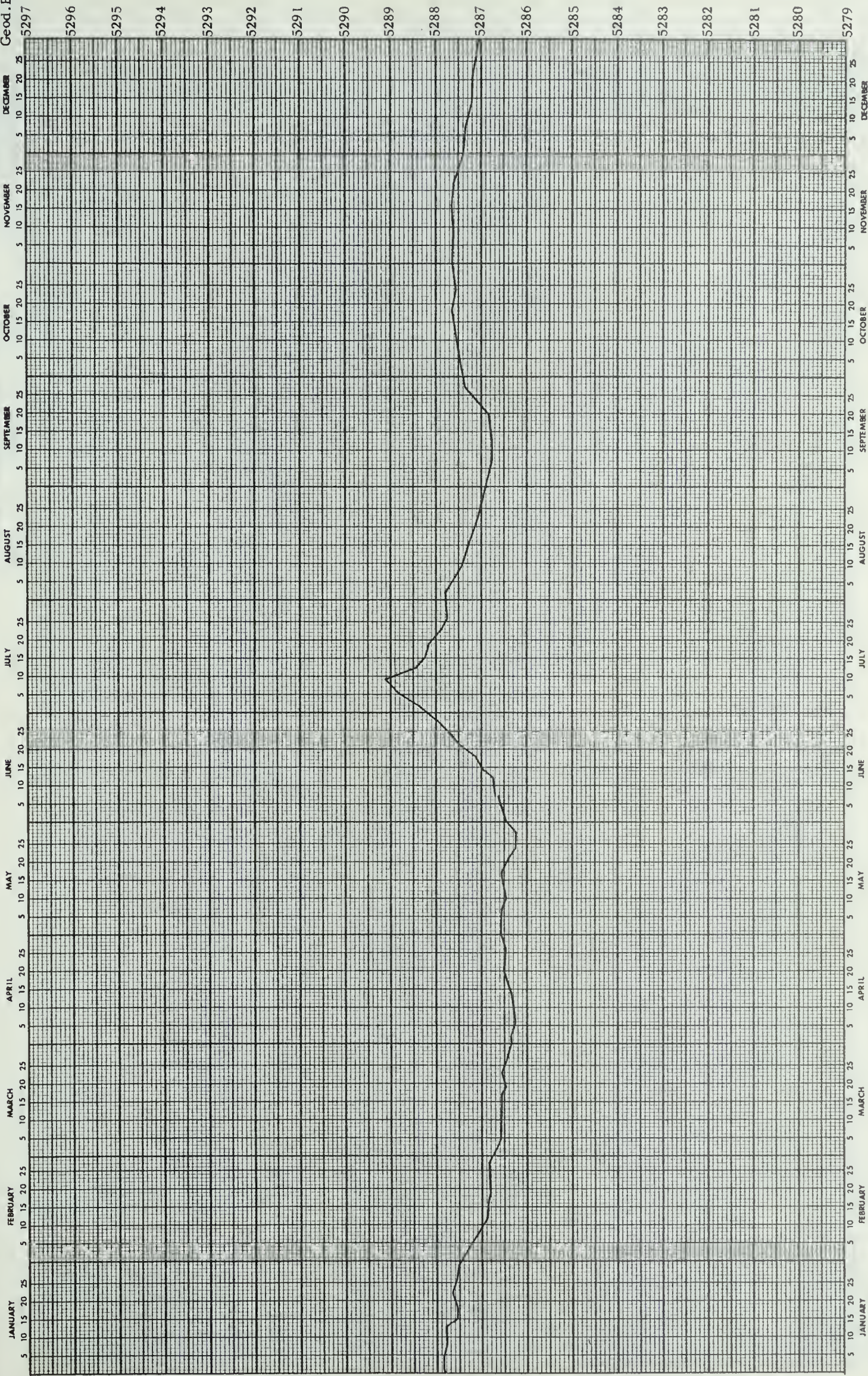
for year ending 31 December 19 65

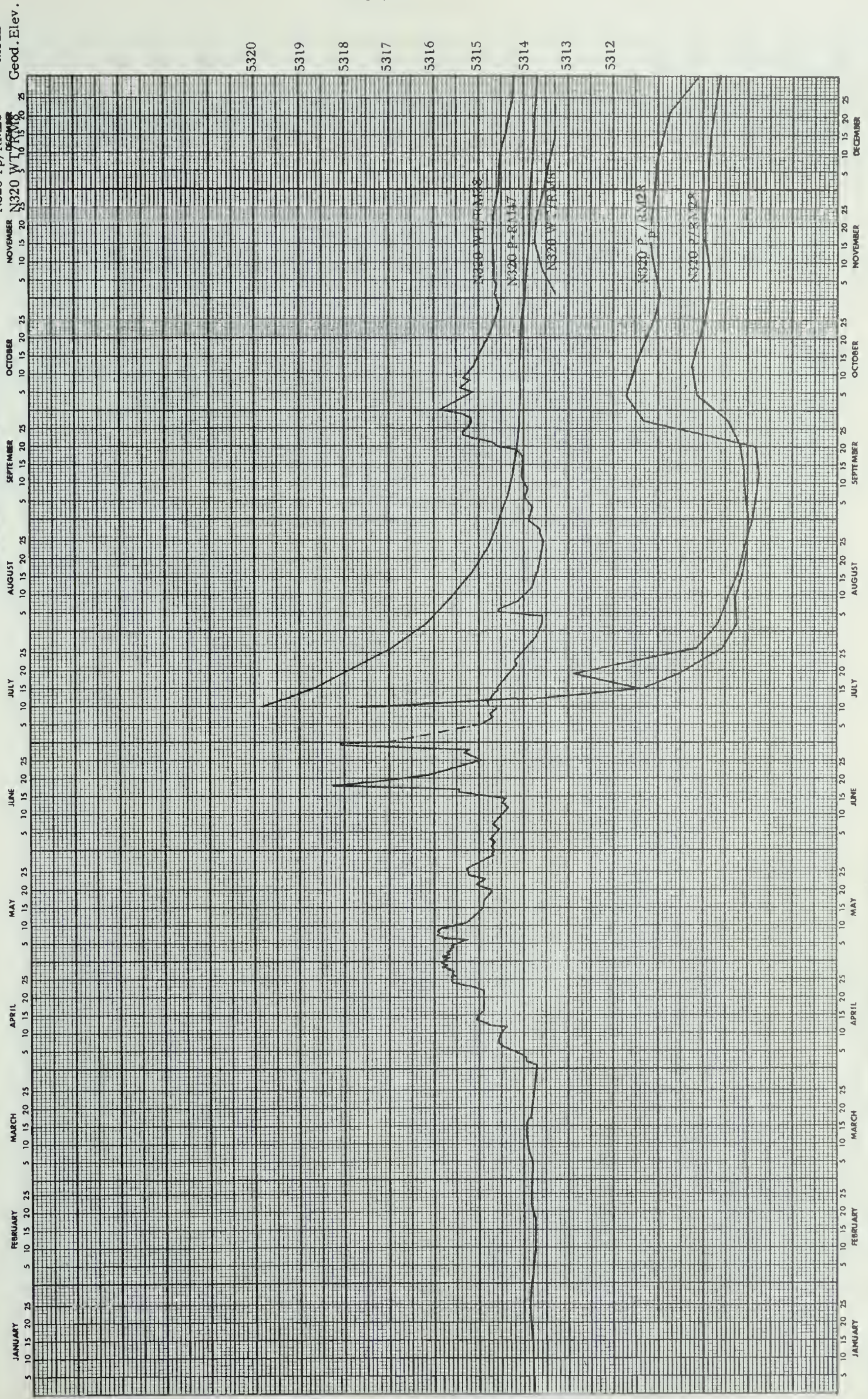


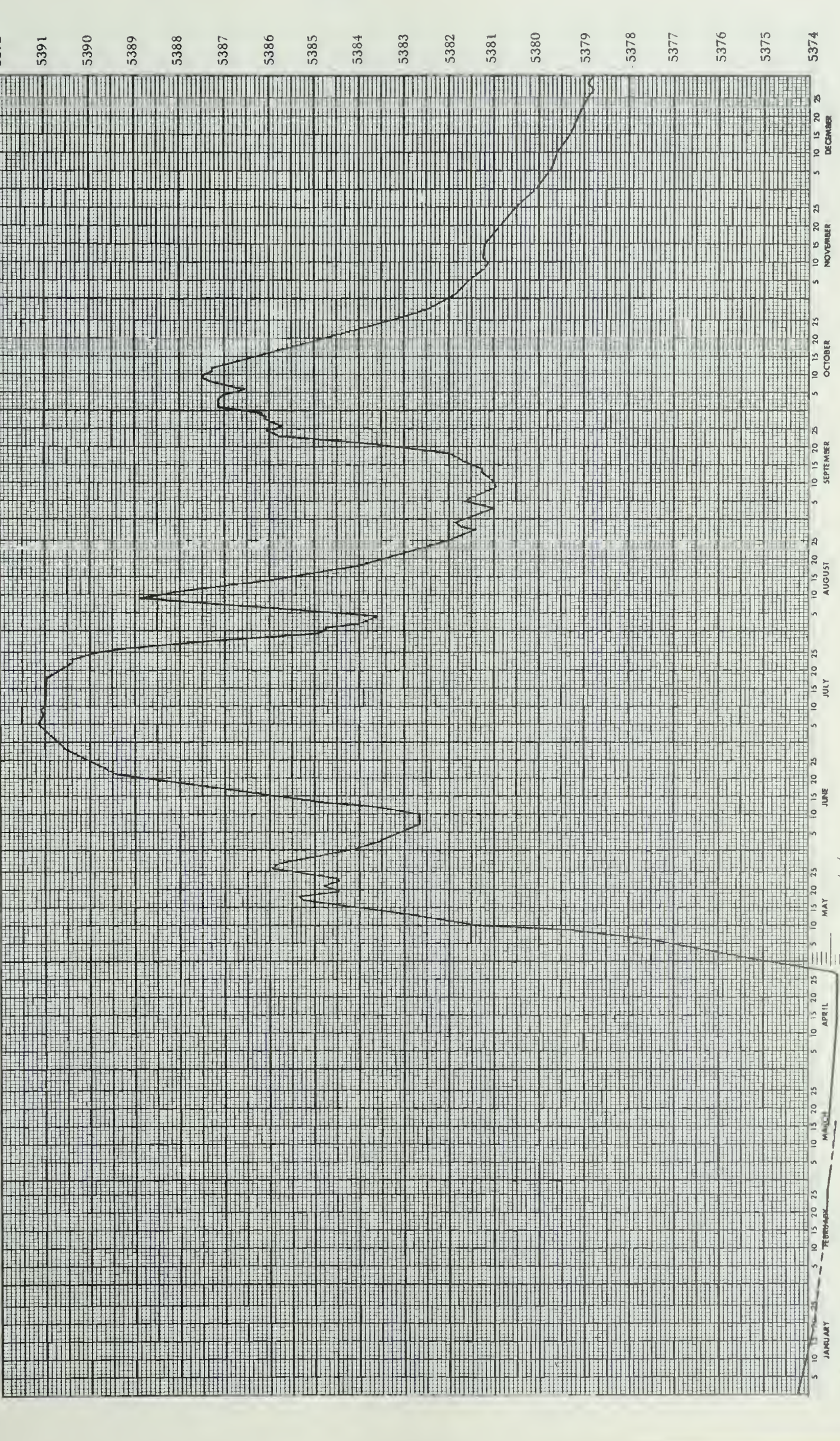
Plotted by _____ Checked by _____ Approved by JRS Date 8/2/66

for year ending 31 December 19 65

Mean
Geod. Elev.

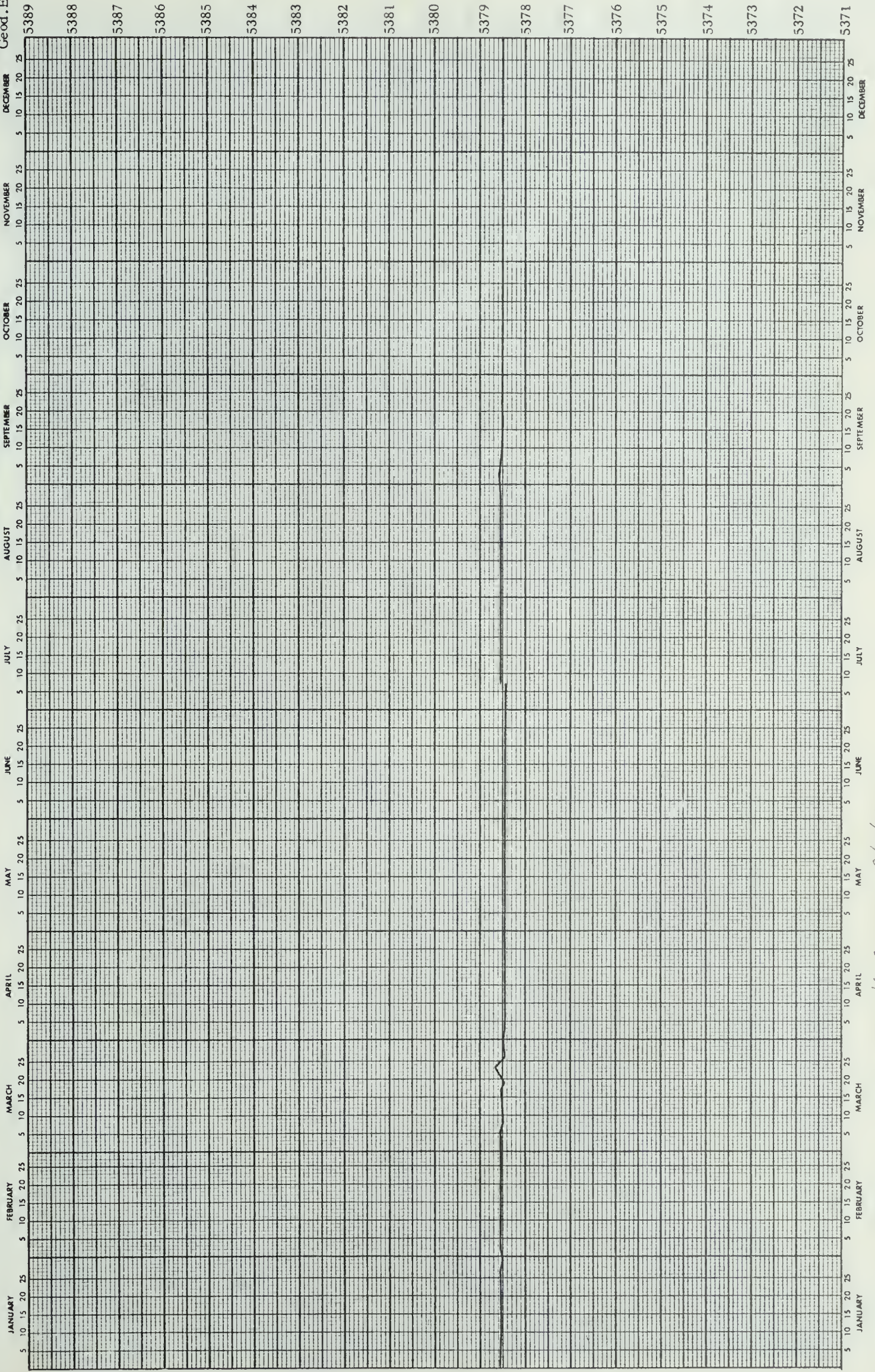




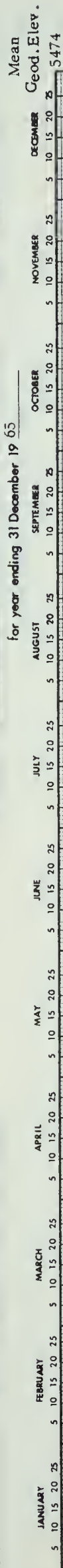


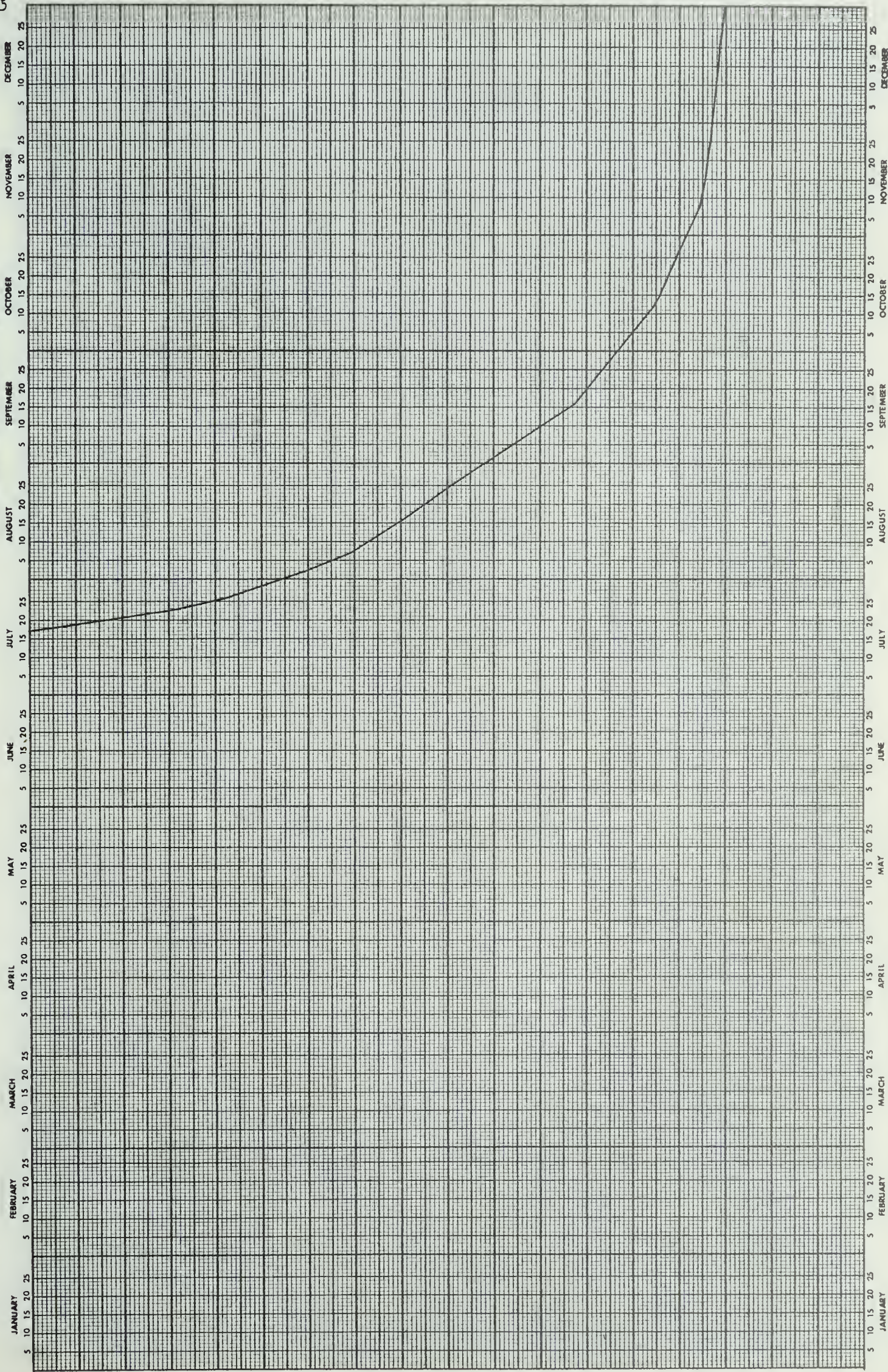
for year ending 31 December 19 65

Mean
Geod. Elev.



for year ending 31 December 19 65



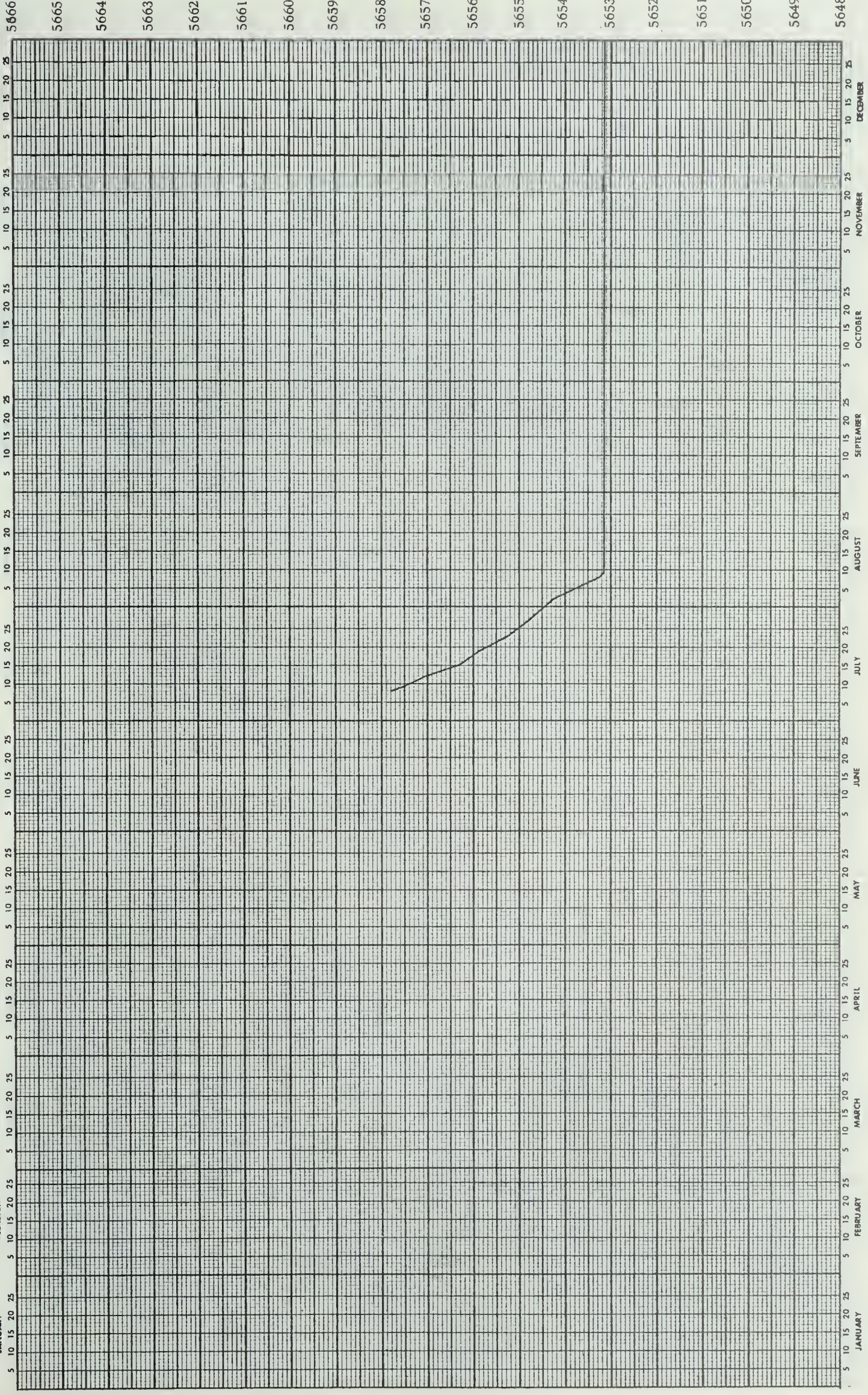


68

for year ending 31 December 19 65

Mean

JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER Geod. Elev. 5666



Plotted by _____ Checked by _____ Approved by WRS Date 8/2/66

for year ending 31 December 19 65

Mean

Geod. Elev.

5813

5812

5811

5810

5809

5808

5807

5806

5805

5804

5803

5802

5801

5800

5799

5798

5797

5796

5795

5794

5793

5792

5791

5790

5789

5788

5787

5786

5785

5784

5783

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5781

5780

5779

5778

5777

5776

5775

5774

5773

5772

5771

5770

5769

5768

5767

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5503

5502

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5496

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5494

5493

5492

5491

5490

5489

5488

5487

5486

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5475

5474

5473

5472

5471

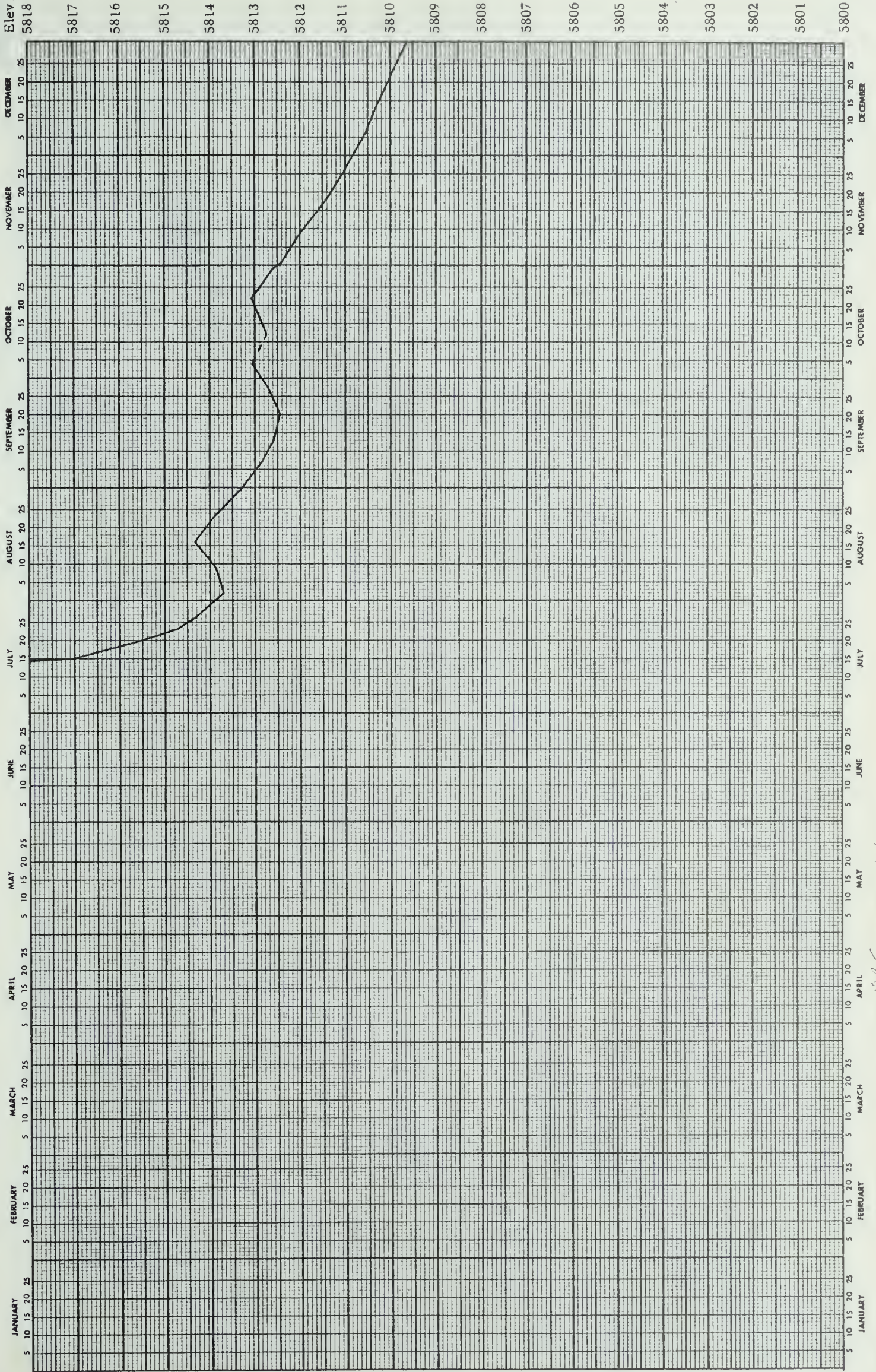
5470

5469

5468

Mean Geod. Elev. 5818

for year ending 31 December 19 65

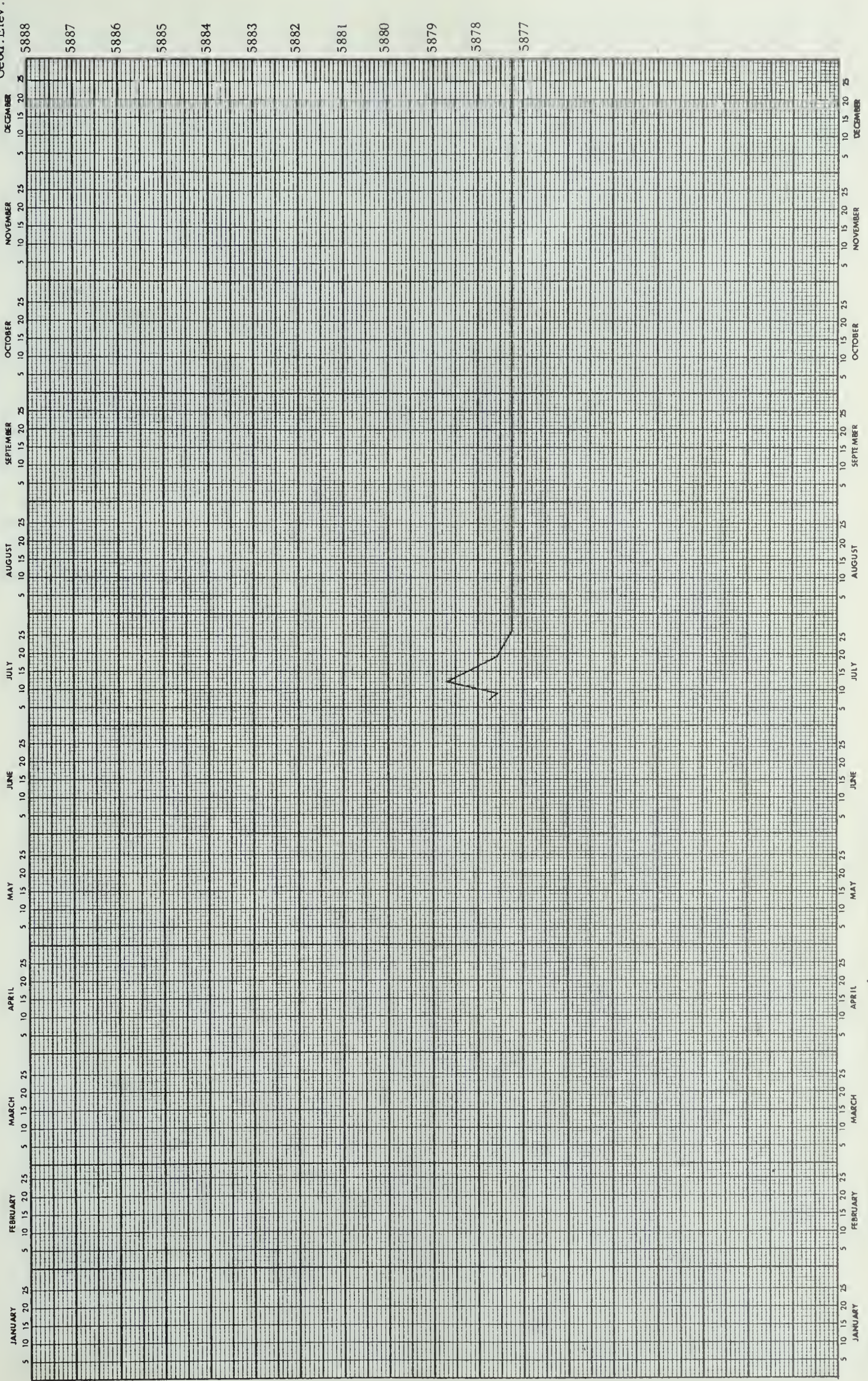


RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. N900 WT-SR24

for year ending 31 December 19 65

Mean
Geod. Elev.



Plotted by _____ Checked by _____ Approved by KLCS Date 8/2/66

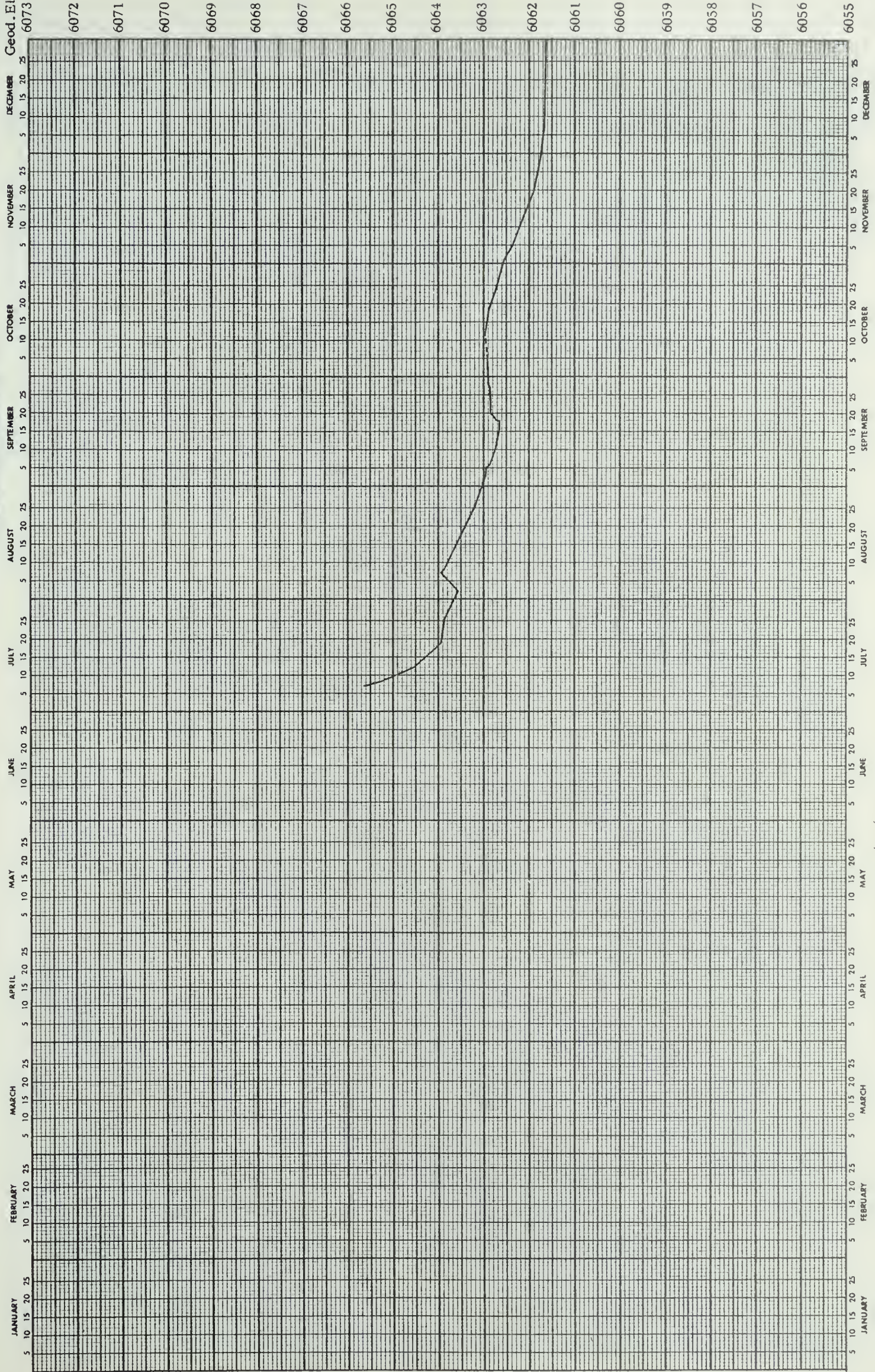
RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. N1080 WT-SR20 R 139A 11-62

for year ending 31 December 1965

Mean

Geod. Elev. 6073



Plotted by _____ Checked by _____ Approved by WKS Date 2/2/66

HYDROGRAPH FOR

MARMOT CREEK BASIN Water-table well

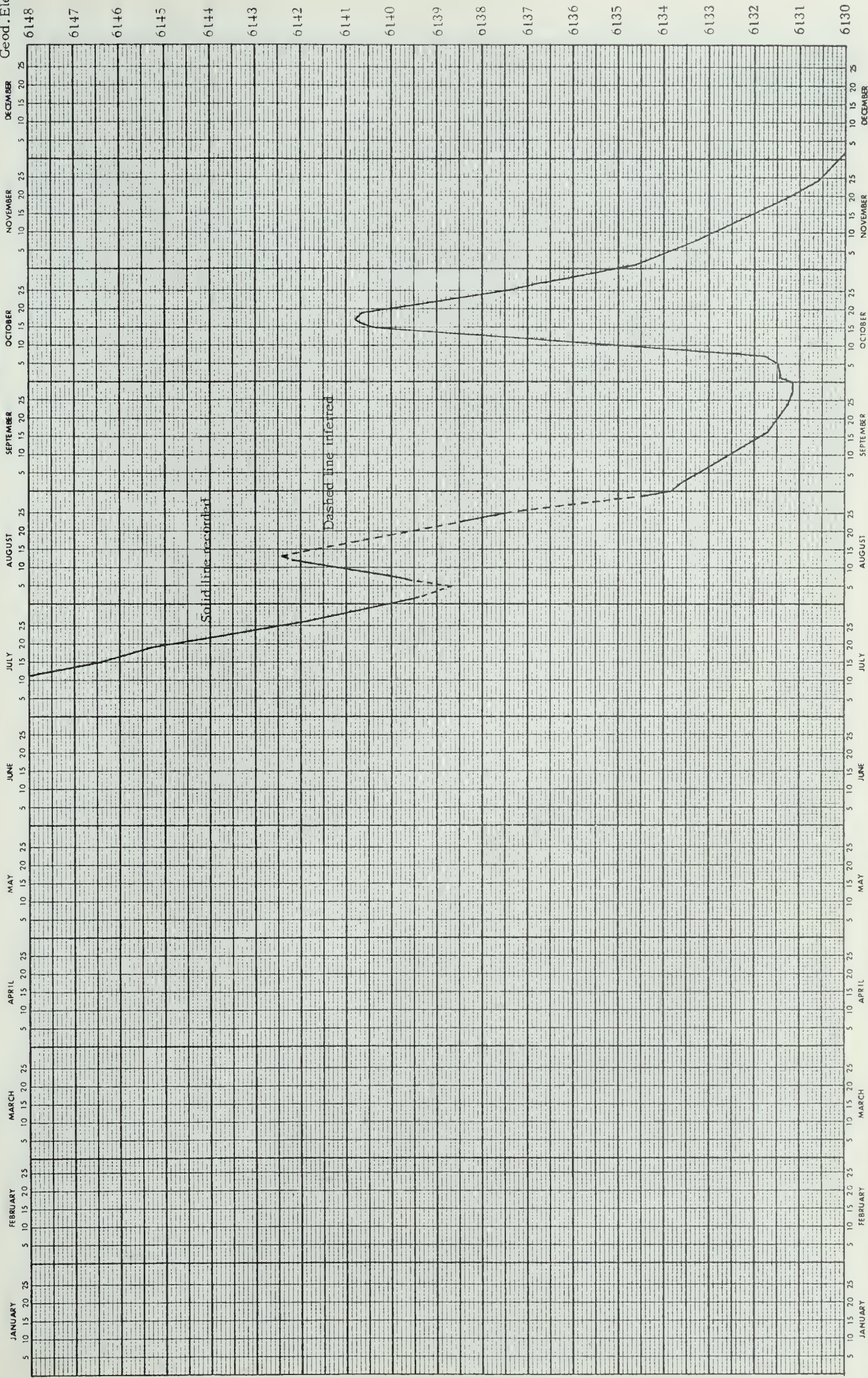
Station No. S1170 WT-F47

R 139 A
1-42

for year ending 31 December 19 65

Mean

Geod. Elev.

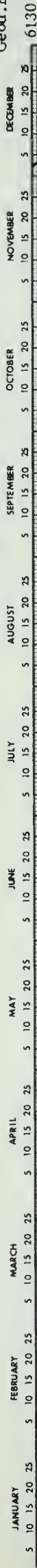


RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. S1170 WT-F47

for year ending 31 December 19 65

Mean
Geod. Elev.



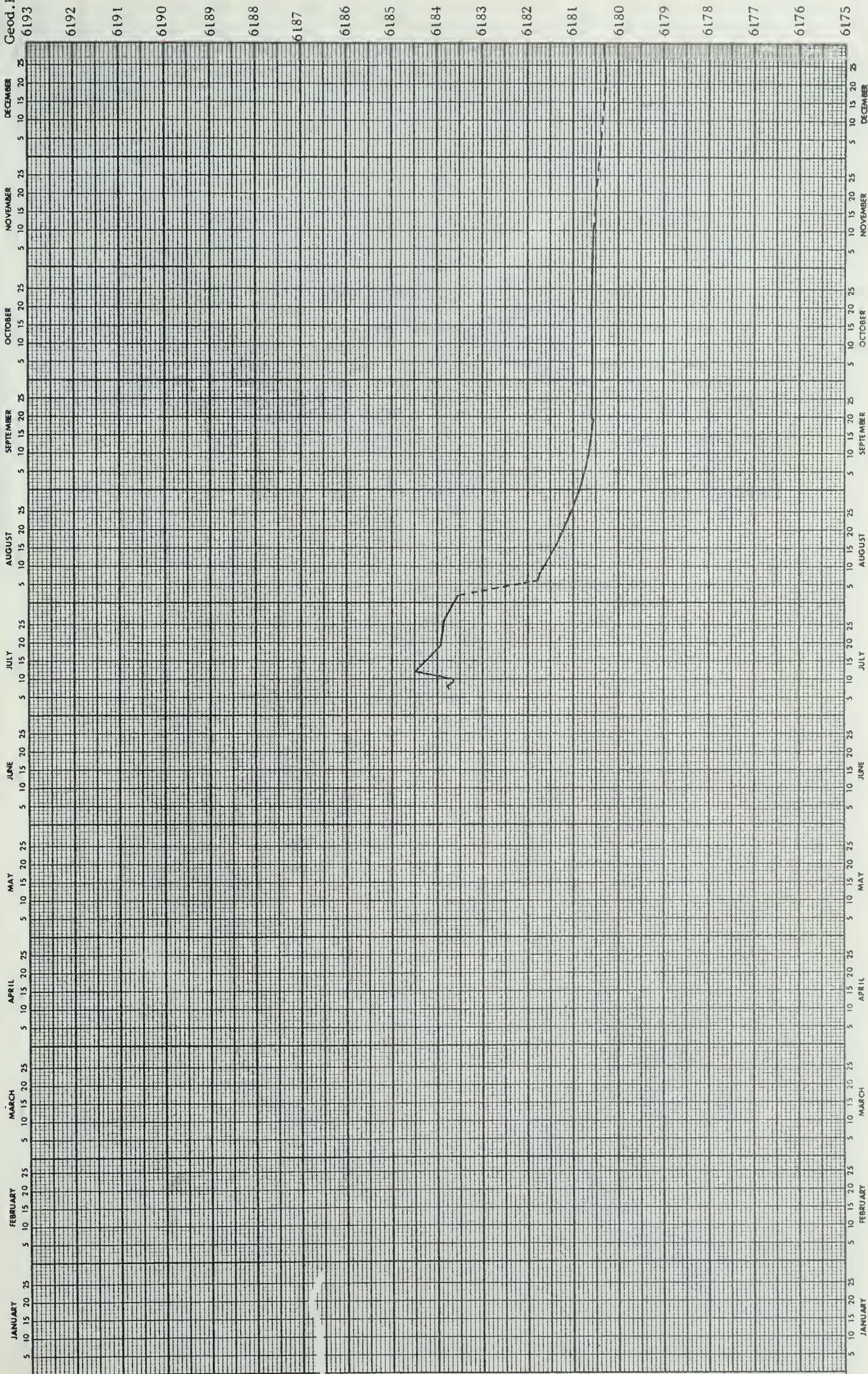
Plotted by _____ Checked by _____ Approved by L.R.S. Date 2/2/66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. N1200 WT-SR22

for year ending 31 December 19 65

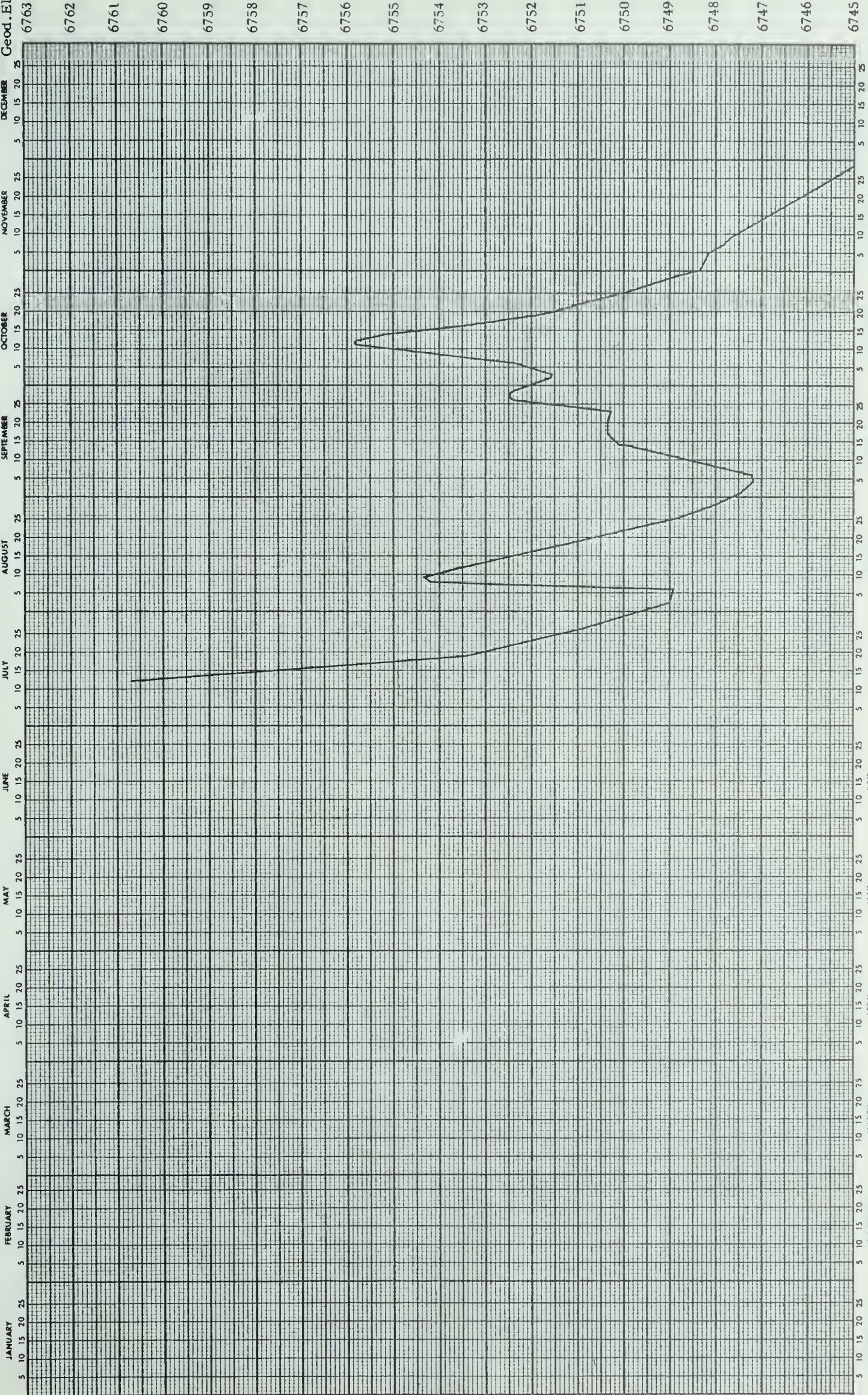
Mean
Geod. Elev.
6193



Plotted by _____ Checked by _____ Approved by WRS Date 8/2/66

for year ending 31 December 19 65

Mean
Geod. Elev.

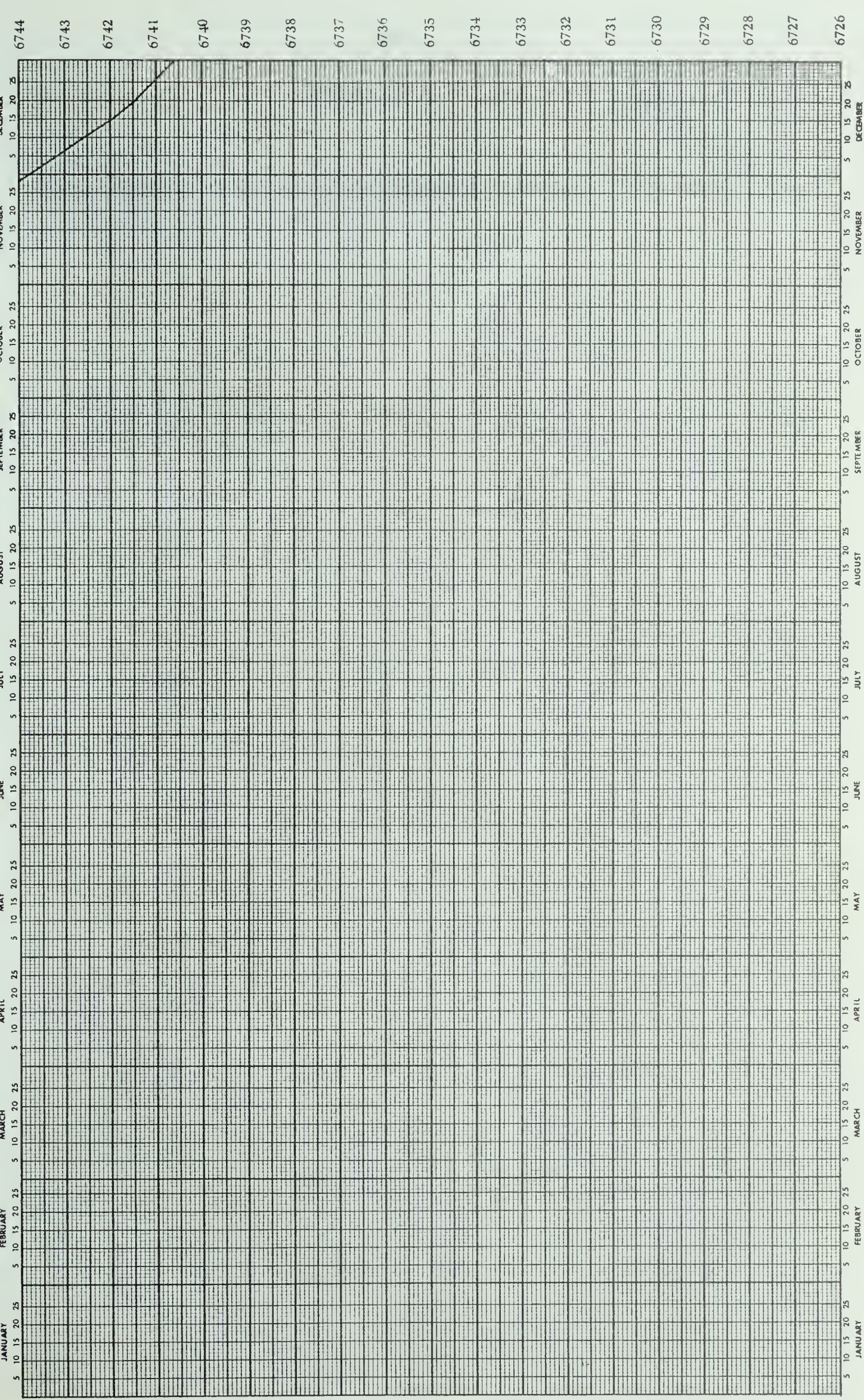


RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. N1770 WT-F38

for year ending 31 December 19 65

Mean
Geod. Elev.



Plotted by _____ Checked by _____ Approved by WLS Date 5/2/66

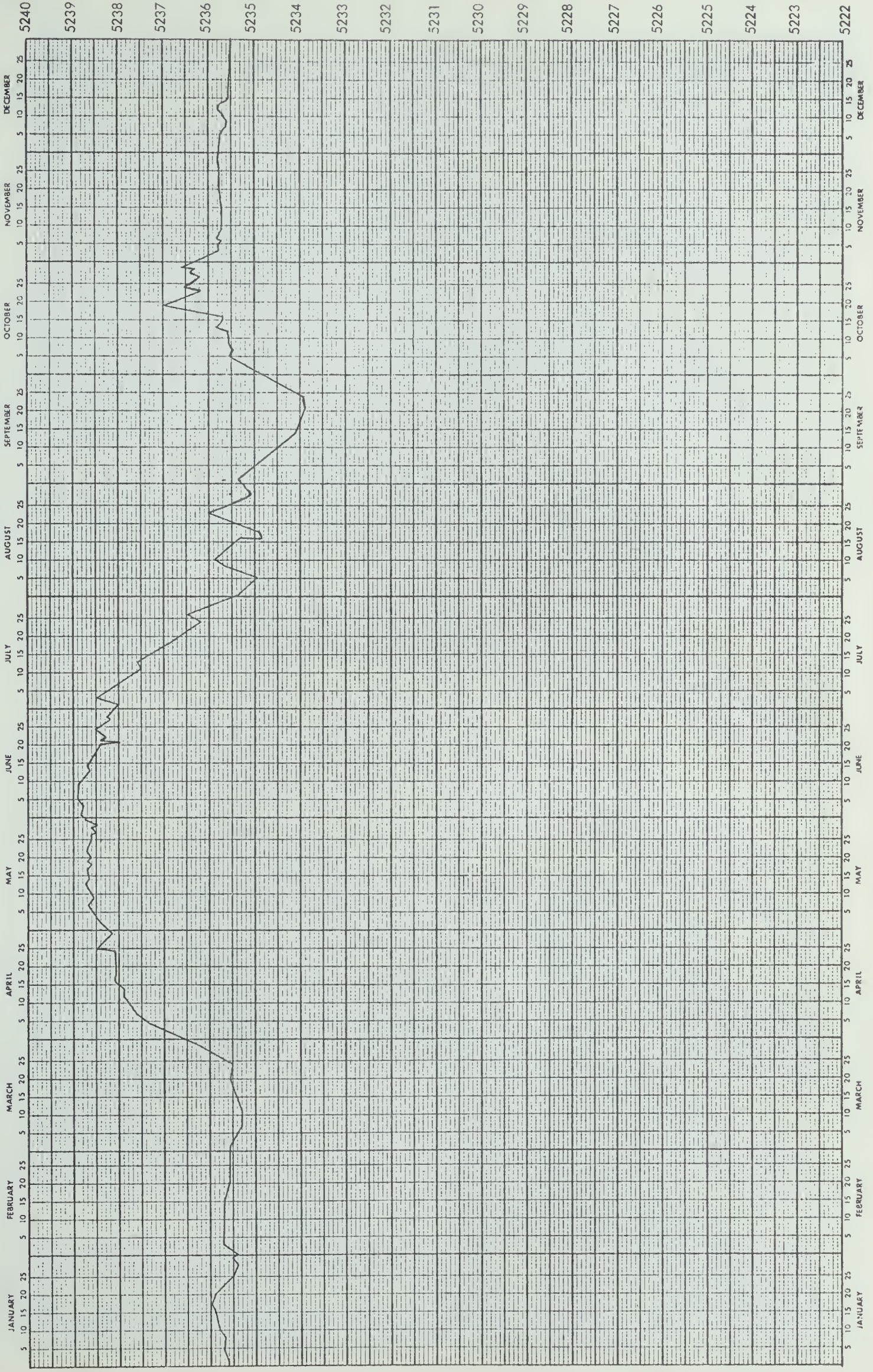
APPENDIX B

Hydrographs of Groundwater Instrumentation in Marmot Creek Basin, 1966.

HYDROGRAPH FOR MARMOT CREEK BASIN

for year ending 31 December 19 66

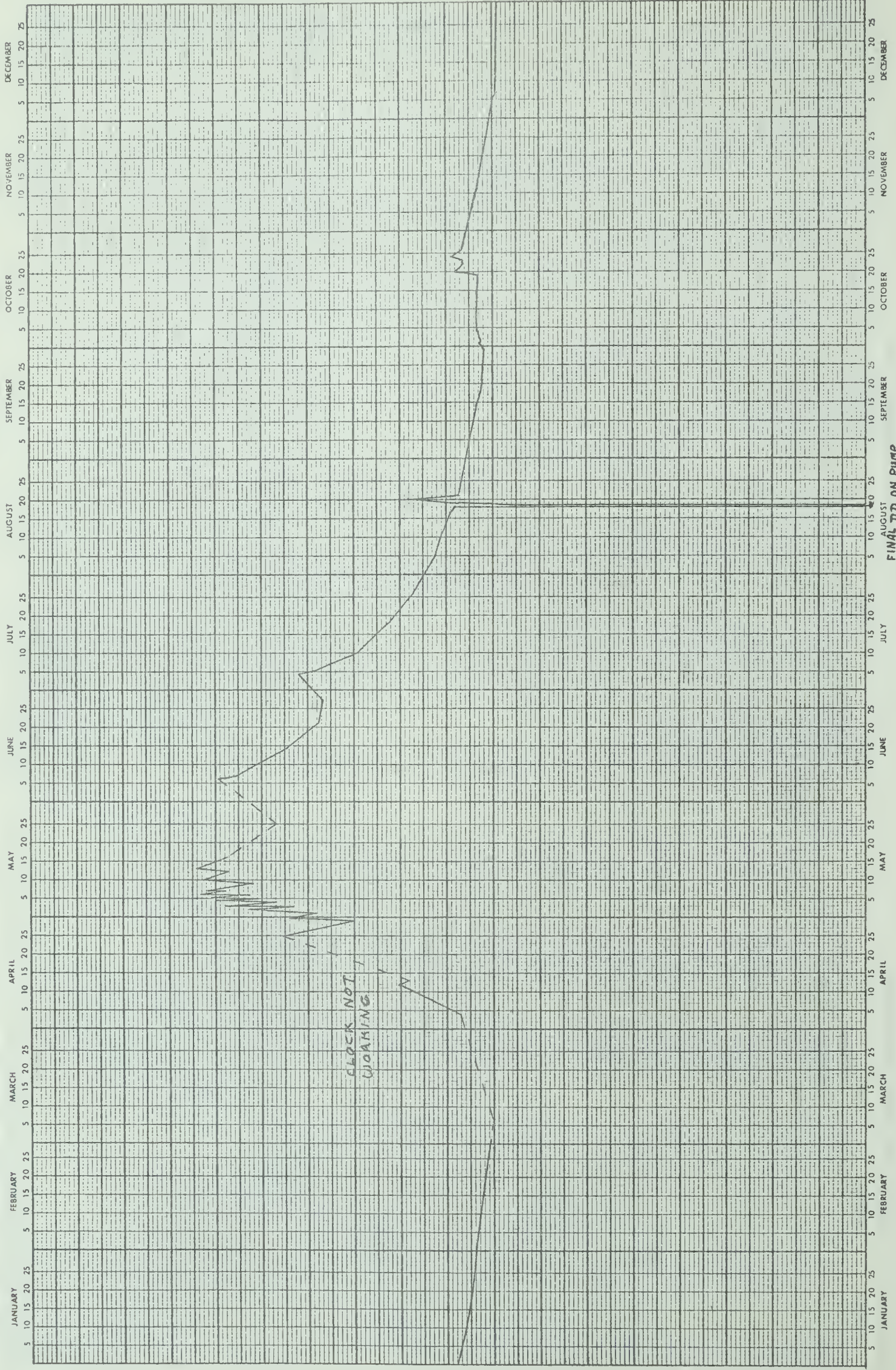
RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION



Plotted by _____ Checked by _____ Approved by _____ Date _____

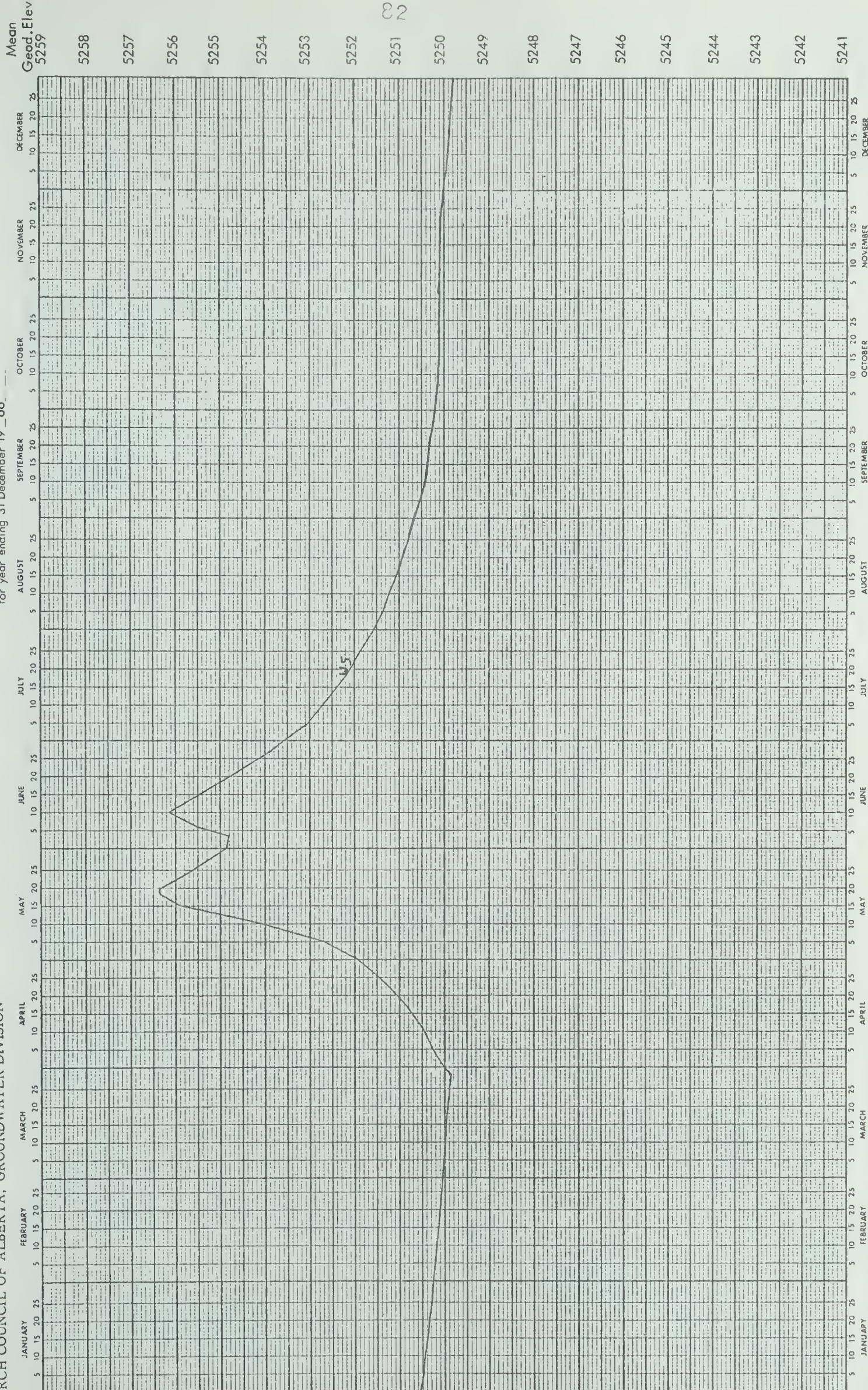
HYDROGRAPH FOR MARMOT CREEK BASIN
for year ending 31 December 19 66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION



Plotted by _____ Checked by _____ Approved by _____ Date _____

FINAL DD ON PUMP
TEST 55-68
5221.68



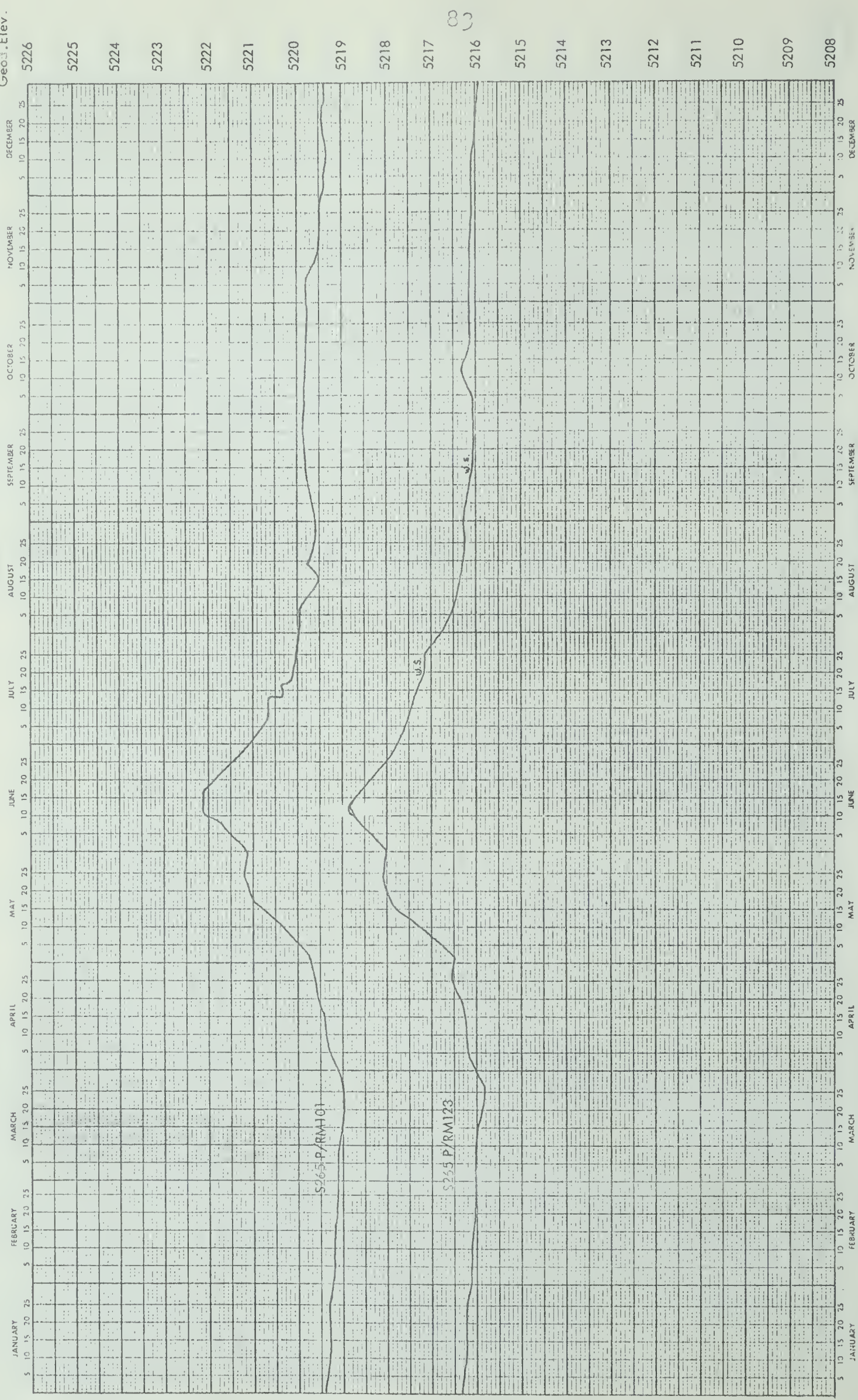
S265P/RM101 REF. PT. 5267.25' A
Station No S265P/RM123 REF. PT. 5265.10

HYDROGRAPH FOR MARMCT CREEK BASIN

for year ending 31 December 1966

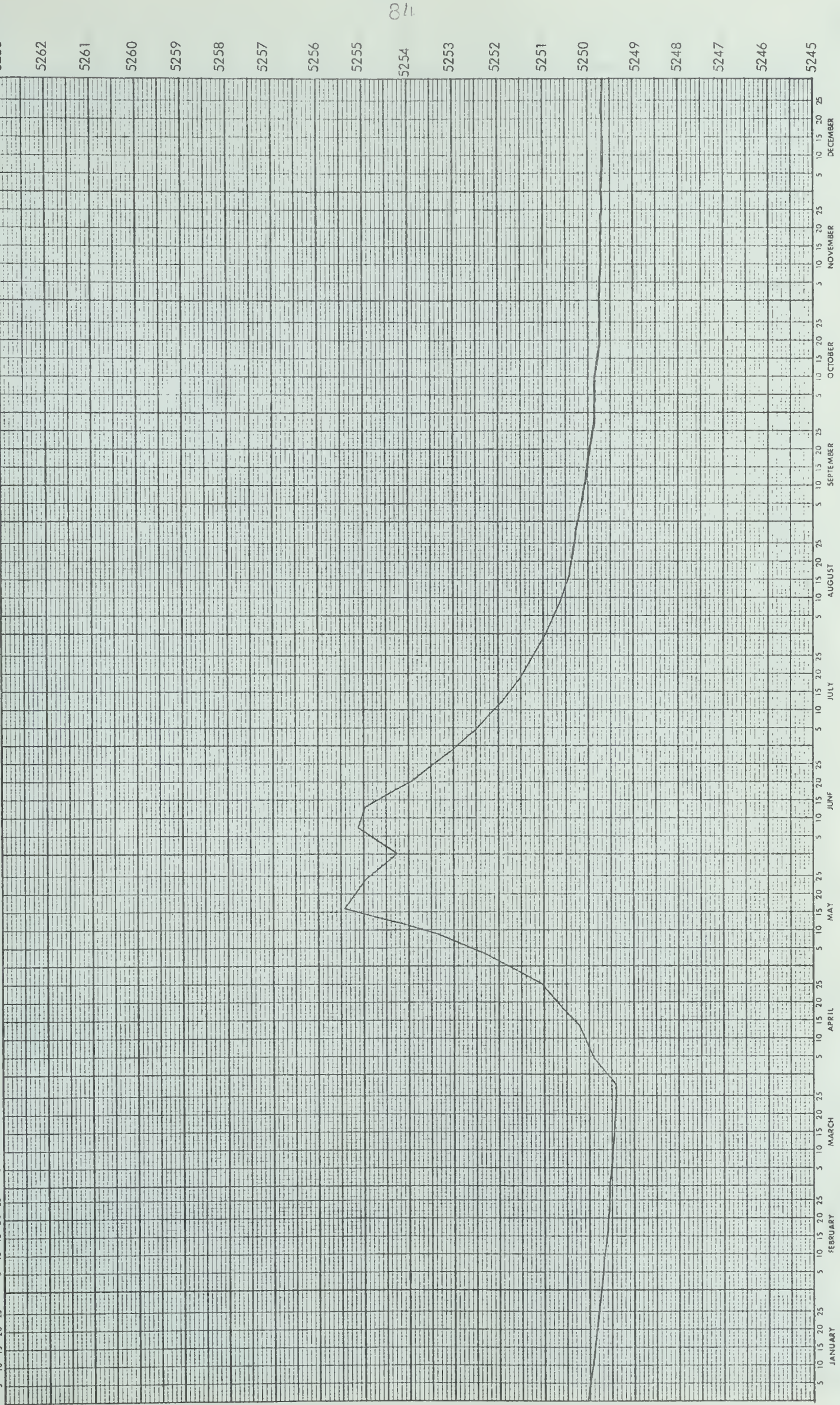
RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

Mean
Geol. Elev.



Plotted by _____ Checked by _____ Approved by _____ Date _____

Mean Elev. 5263

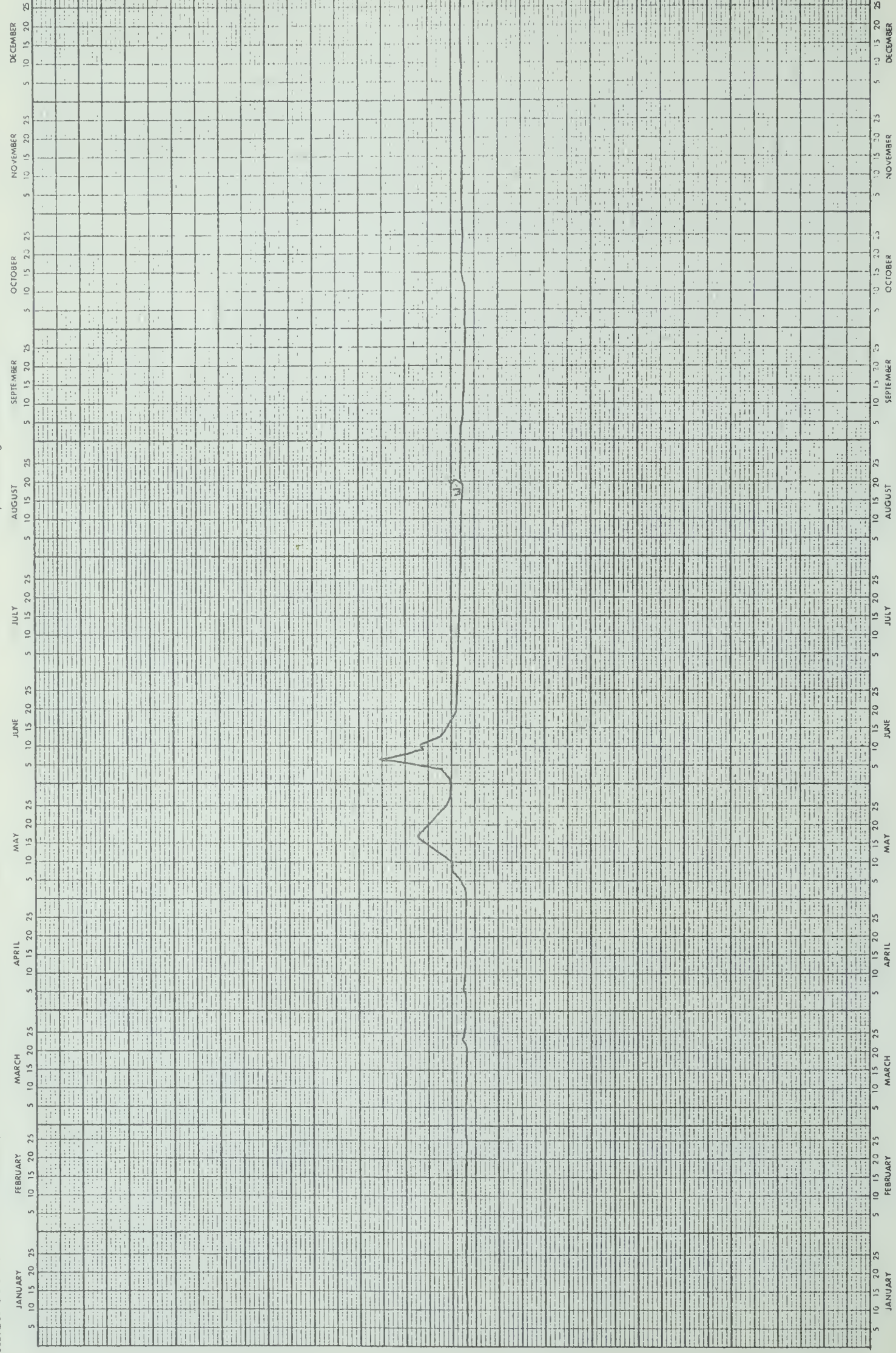


Plotted by _____ Checked by _____ Approved by _____ Date _____

81

Mean
Geod. Elev.

5300
5299
5298
5297
5296
5295
5294
5293
5292
5291
5290
5289
5288
5287
5286



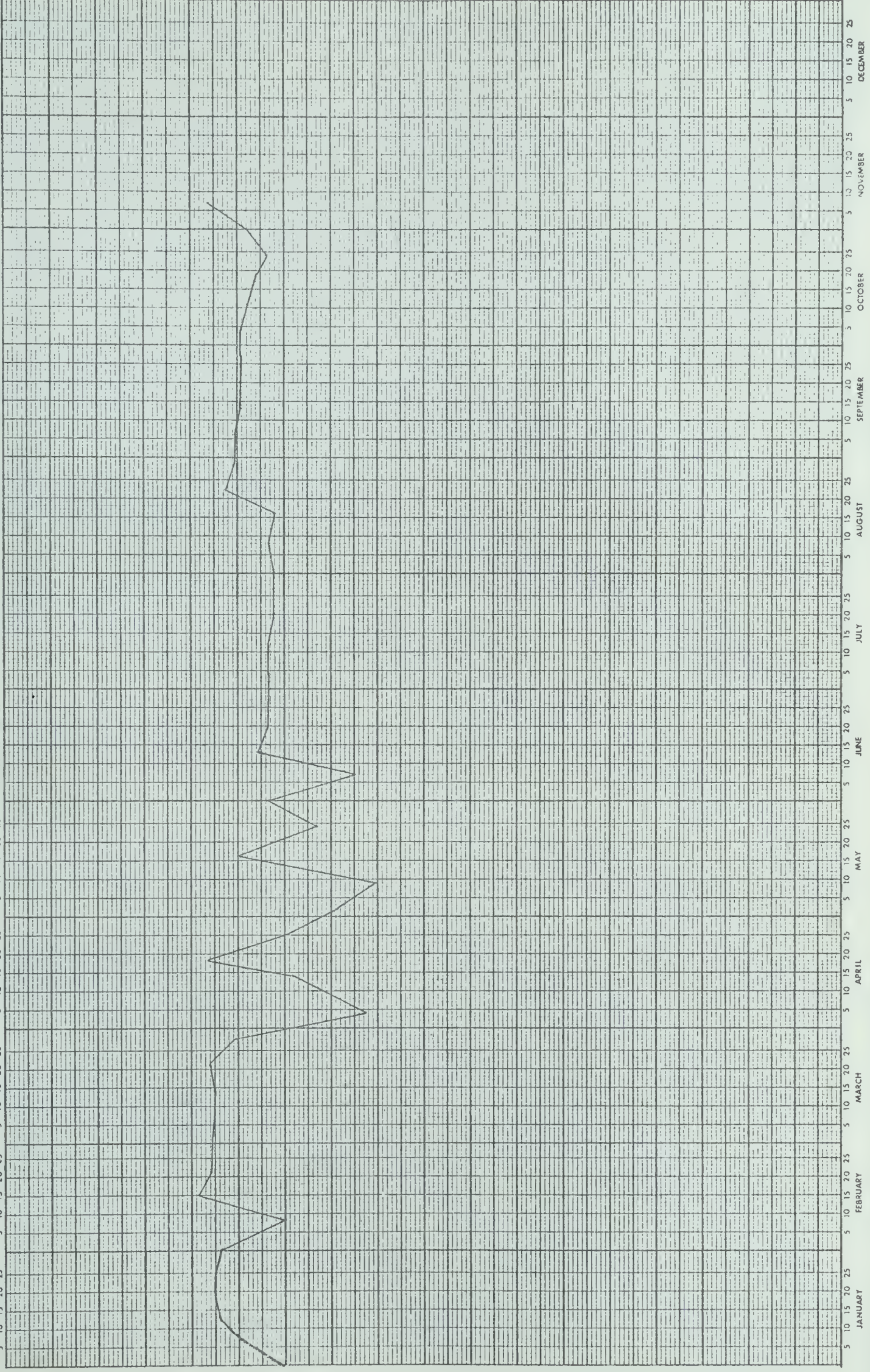
Plotted by _____ Checked by _____ Approved by _____ Date _____

HYDROGRAPH FOR MARMOI CREEK BASIN Piezometer
for year ending 31 December 19 66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

Station No 5300 P 40/RM 21

Depth from
top of casing

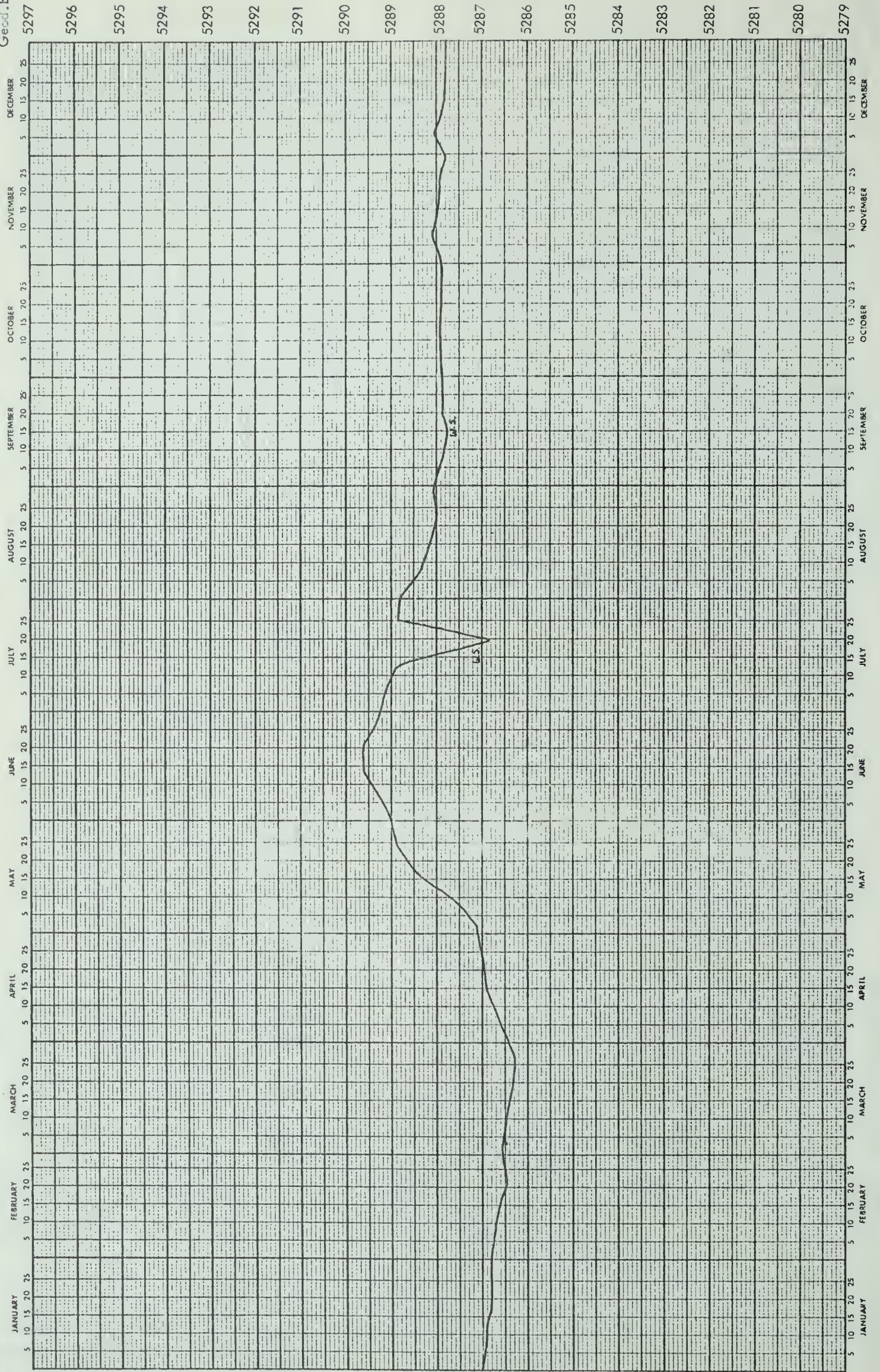


Plotted by _____ Checked by _____ Approved by _____ Date _____

HYDROGRAPH FOR MARMOT CREEK BASIN

for year ending 31 December 19 66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION



Plotted by _____ Checked by _____ Approved by _____ Date _____

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

Water-table wells
HYDROGRAPH FOR MARMOT CREEK BASIN Piezometers
for year ending 31 December 19 66

N320 WT/RM38 REF. PT. 5316.33
N320 P-RM47 REF. PT. 5315.75
N320 P/RM28 REF. PT. 5316.02
N320 Pp/RM28 REF. PT. 5316.04
N320 WT/RM38 REF. PT. 5315.53



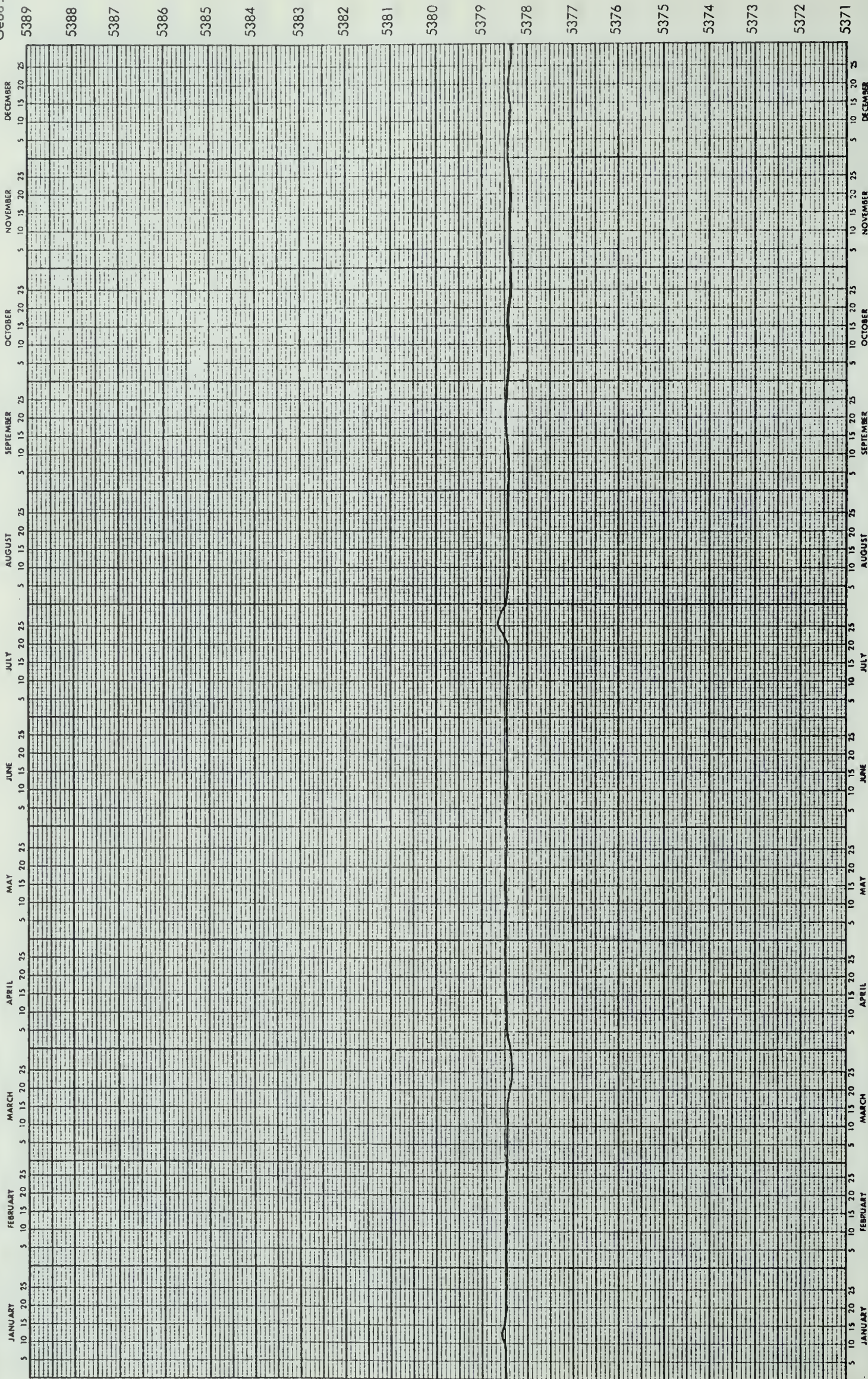
Plotted by _____ Checked by _____ Approved by _____ Date _____

Station No. S400 P-SR32 REF. PT. 5421.92
Mean
Geod. Elev.

HYDROGRAPH FOR MARMOT CREEK BASIN

for year ending 31 December 19 66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION



Plotted by _____ Checked by _____ Approved by _____ Date _____

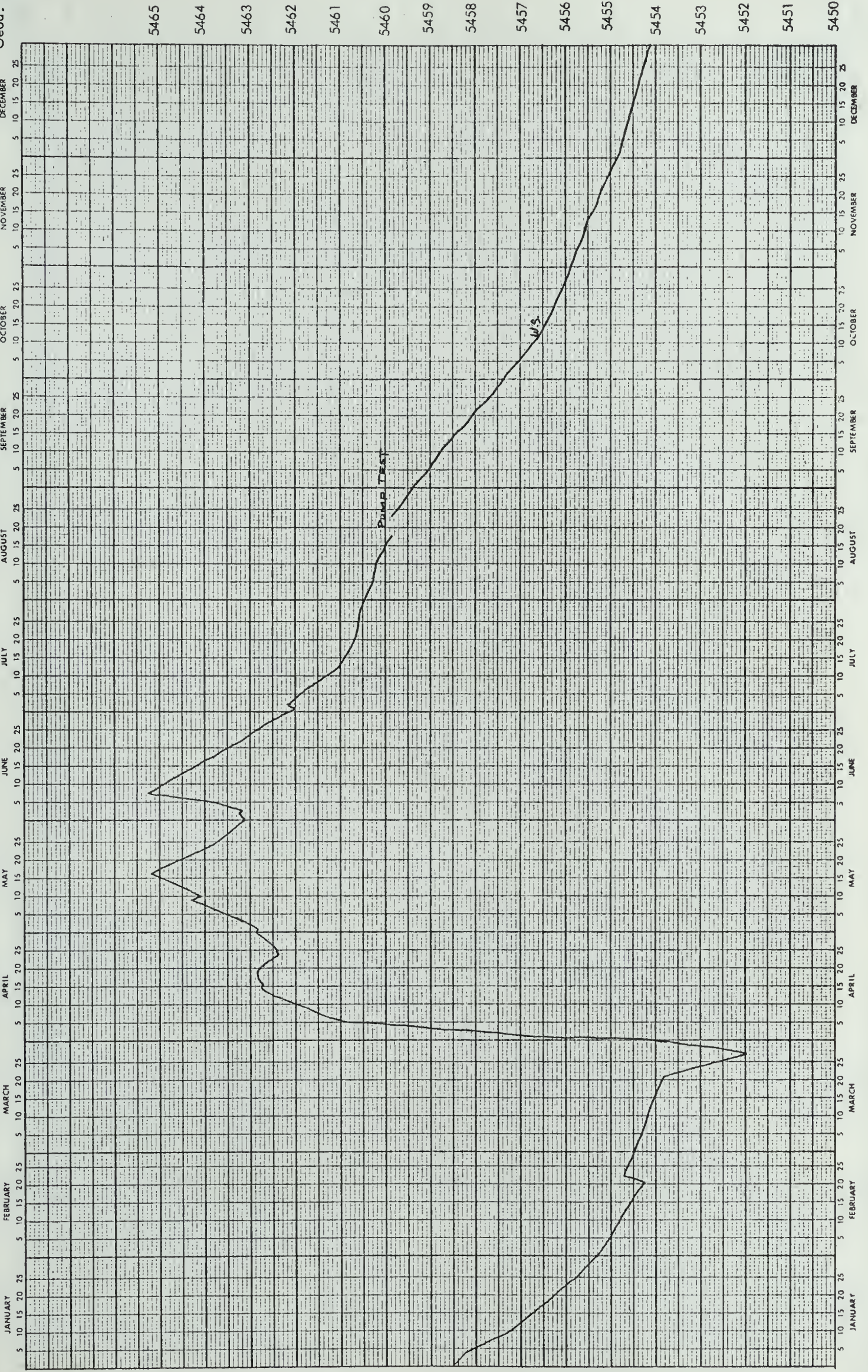
HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No N475 WT-RM120

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

for year ending 31 December 19 66

Mean Geod. Elev.

90



Plotted by _____ Checked by _____ Approved by _____ Date _____

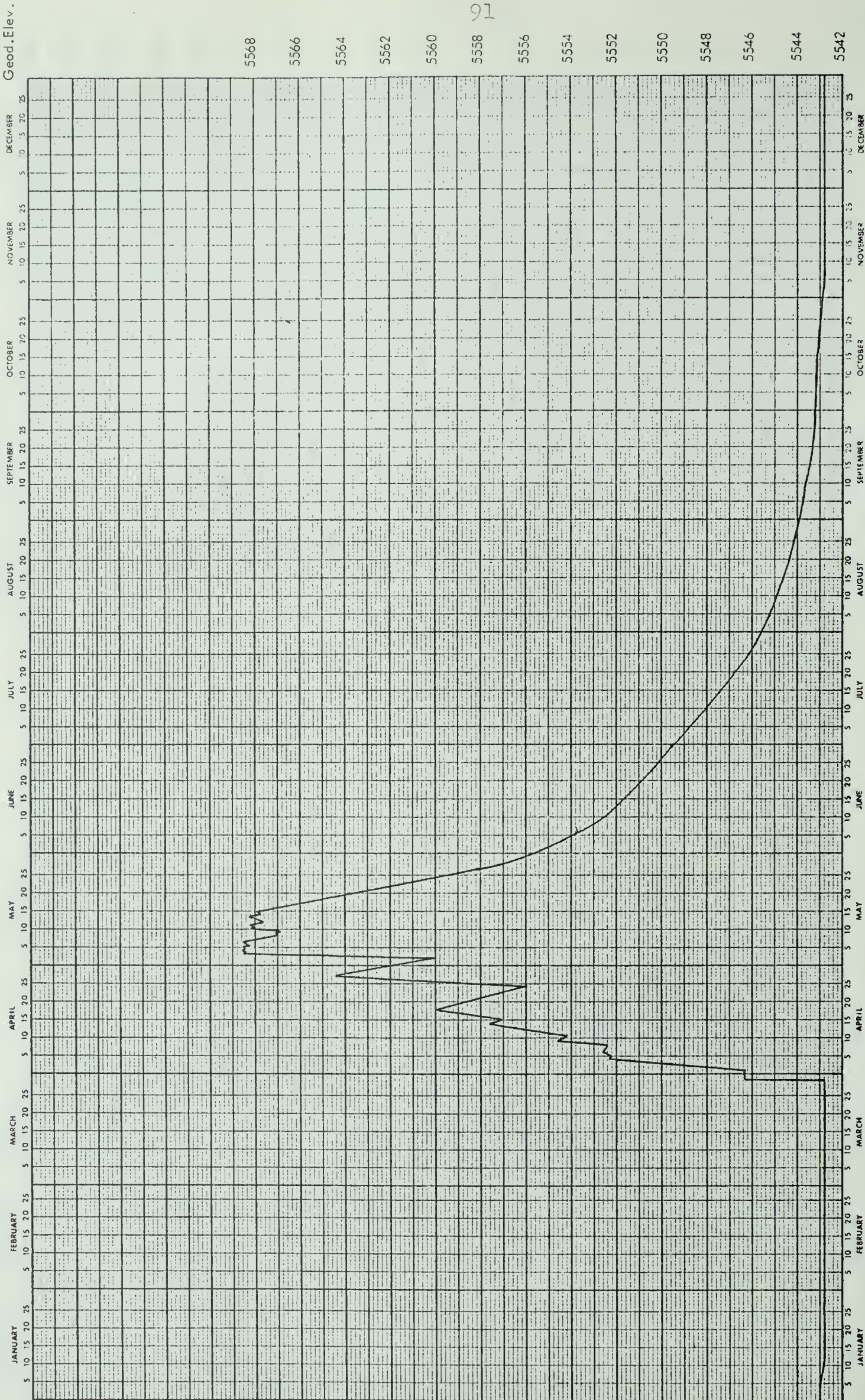
Station No S570 WT-Sp29

HYDROGRAPH FOR MARMCT CREEK BASIN Water-table well

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

for year ending 31 December 1966

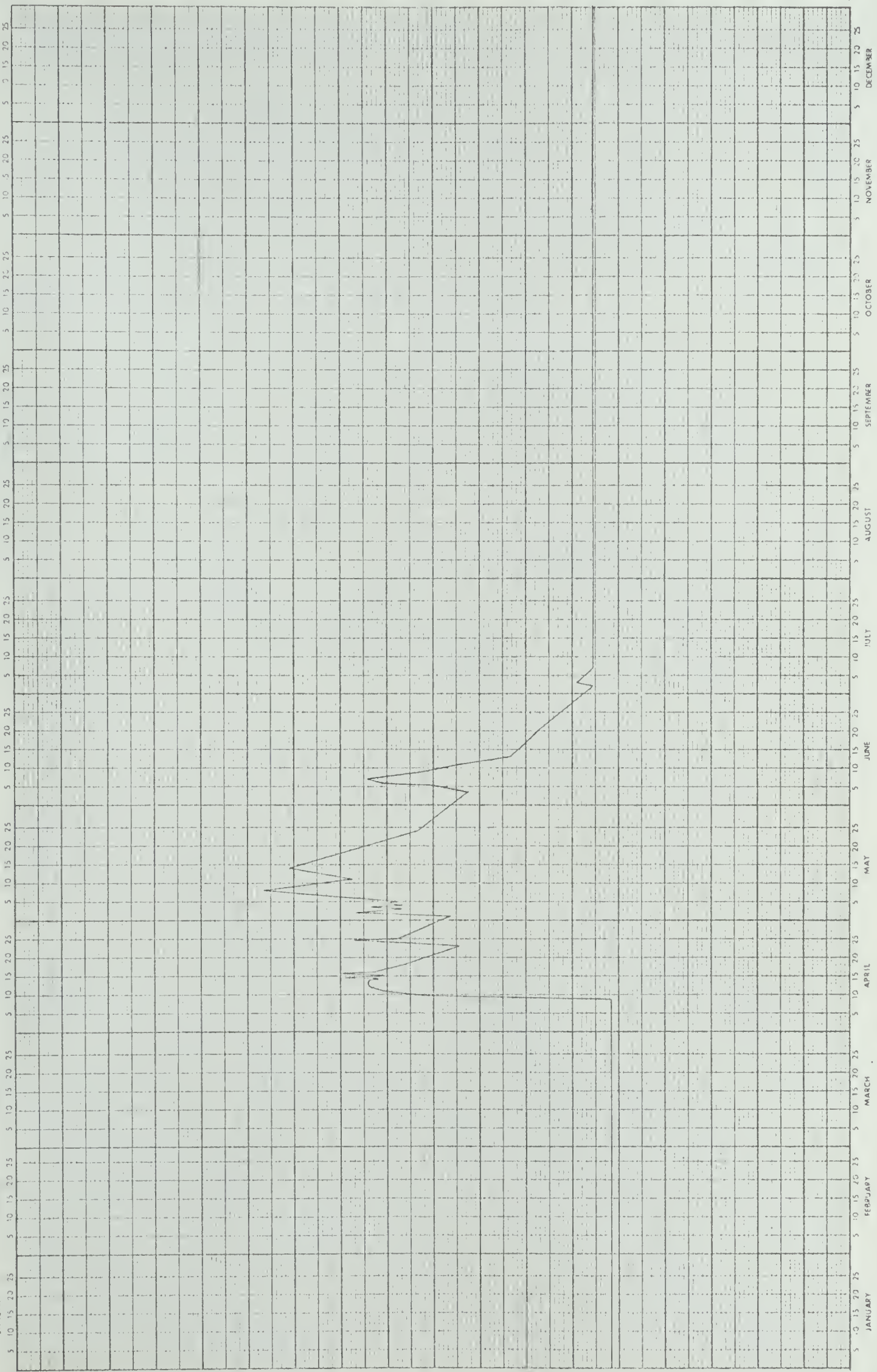
Mean
Geod. Elev.



Plotted by _____ Checked by _____ Approved by _____ Date _____

for year ending 31 December 19 66

Mean
Geod. Elev.



Plotted by _____ Checked by _____ Approved by _____ Date _____

HYDROGRAPH FOR MARMOT CREEK BASIN

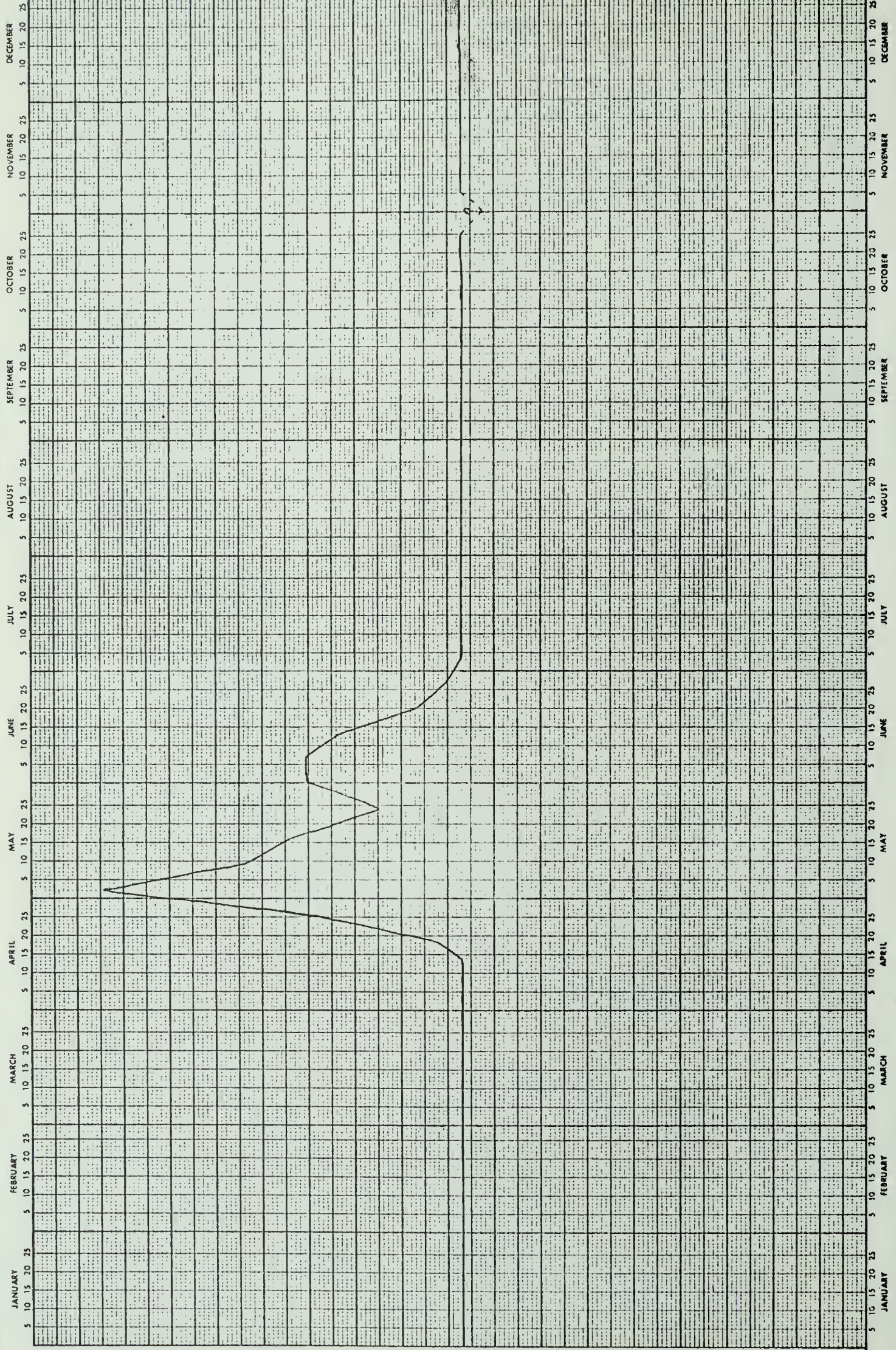
RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

for year ending 31 December 19 66

Station No. N820 WT-SR20

Mean
Geod. Elev.,

5813
5812
5811
5810
5809
5808
5807
5806
5805
5804
5803
5802
5801
5800
5799
5798
5797
5796
5795



Plotted by _____ Checked by _____ Approved by _____ Date _____

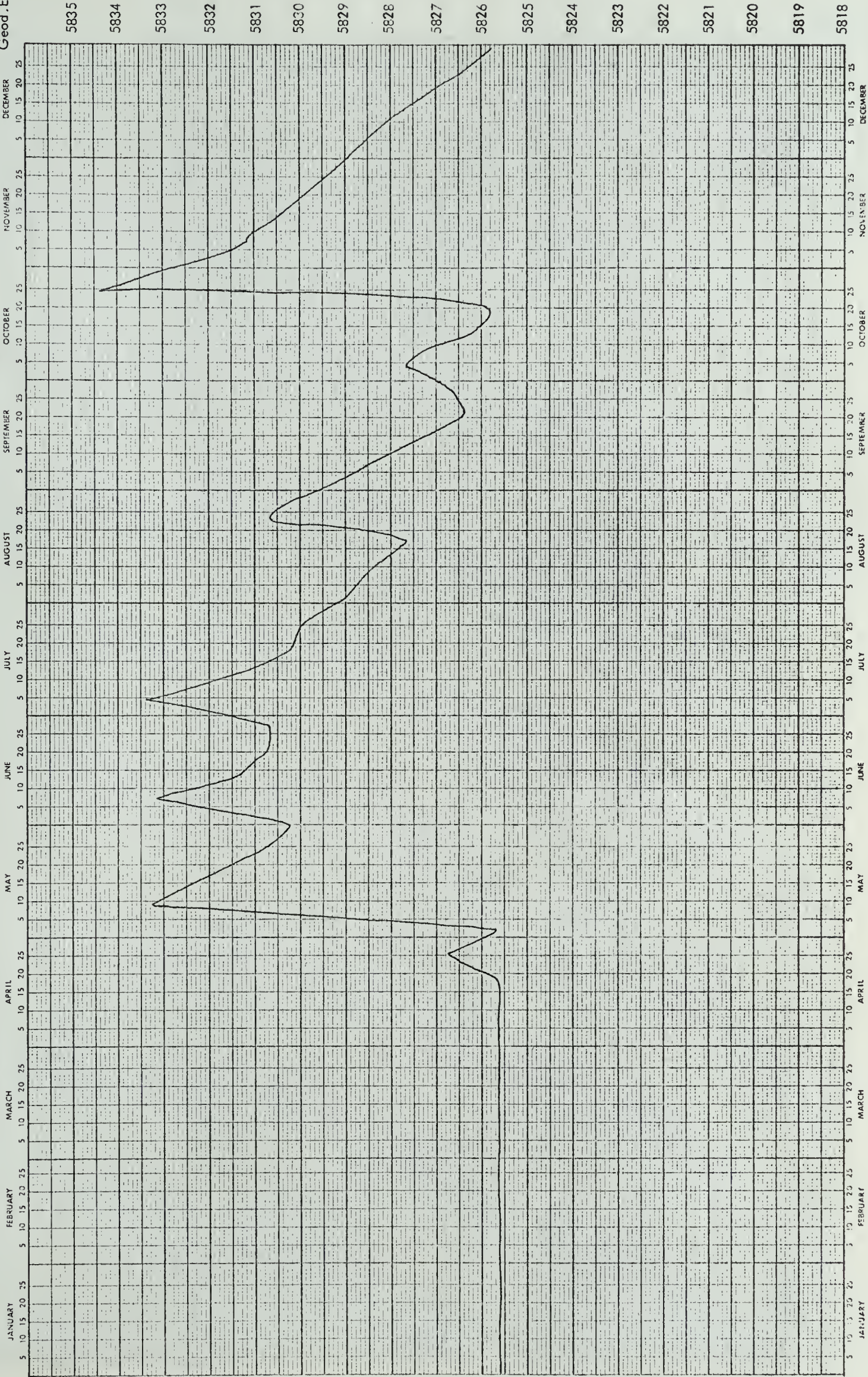
Station No. 5835 WT/F19

HYDROGRAPH FOR MARMOT CREEK BASIN

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

for year ending 31 December 19 66

Mean
Geod. Elev.



Plotted by _____ Checked by _____ Approved by _____ Date _____

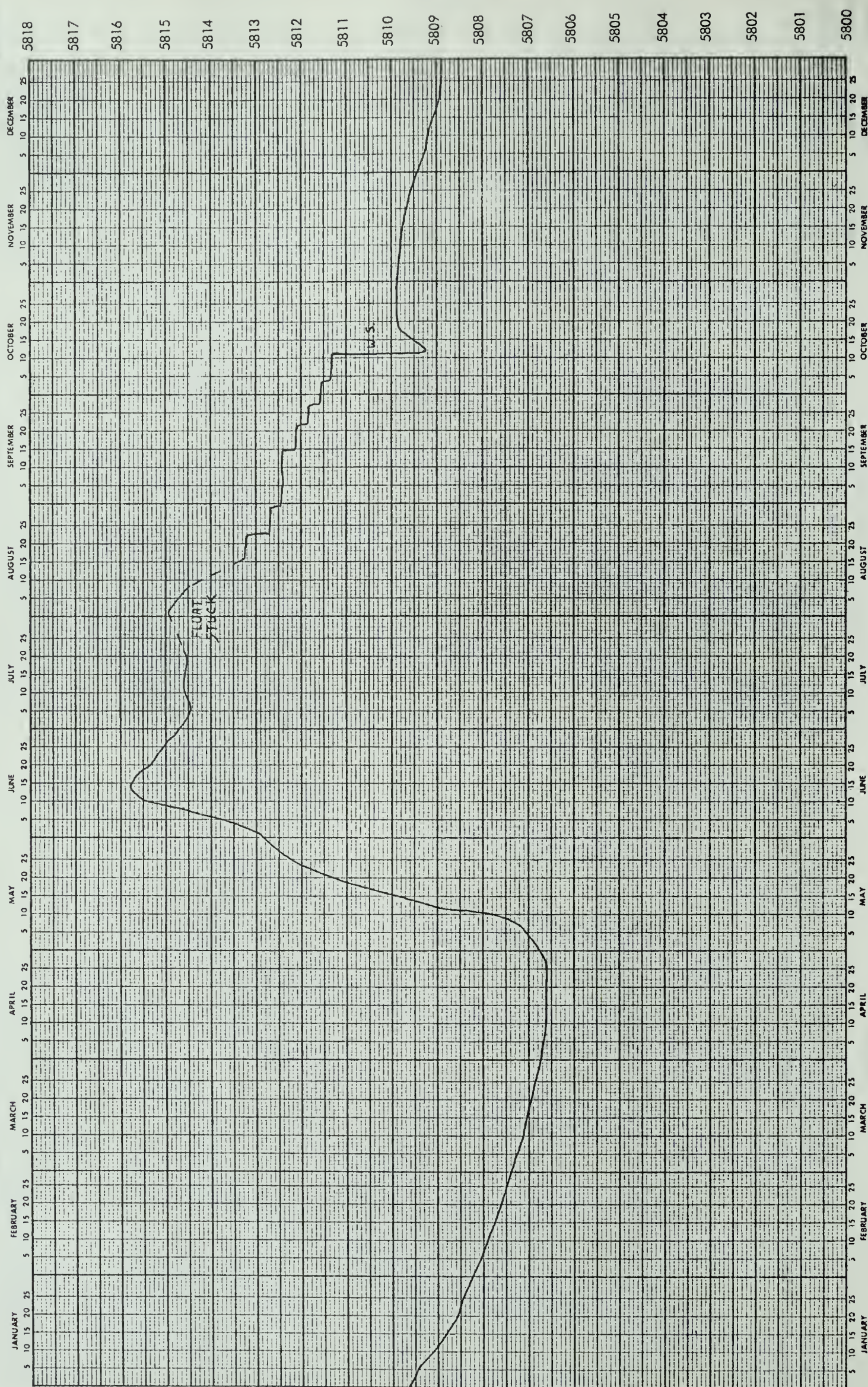
Mean
Geod. Elev.

Station No. 5835 P-F40

HYDROGRAPH FOR MARMOT CREEK BASIN

for year ending 31 December 19 66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION



Plotted by _____ Checked by _____ Approved by _____ Date _____

HYDROGRAPH FOR MARMOT CREEK BASIN

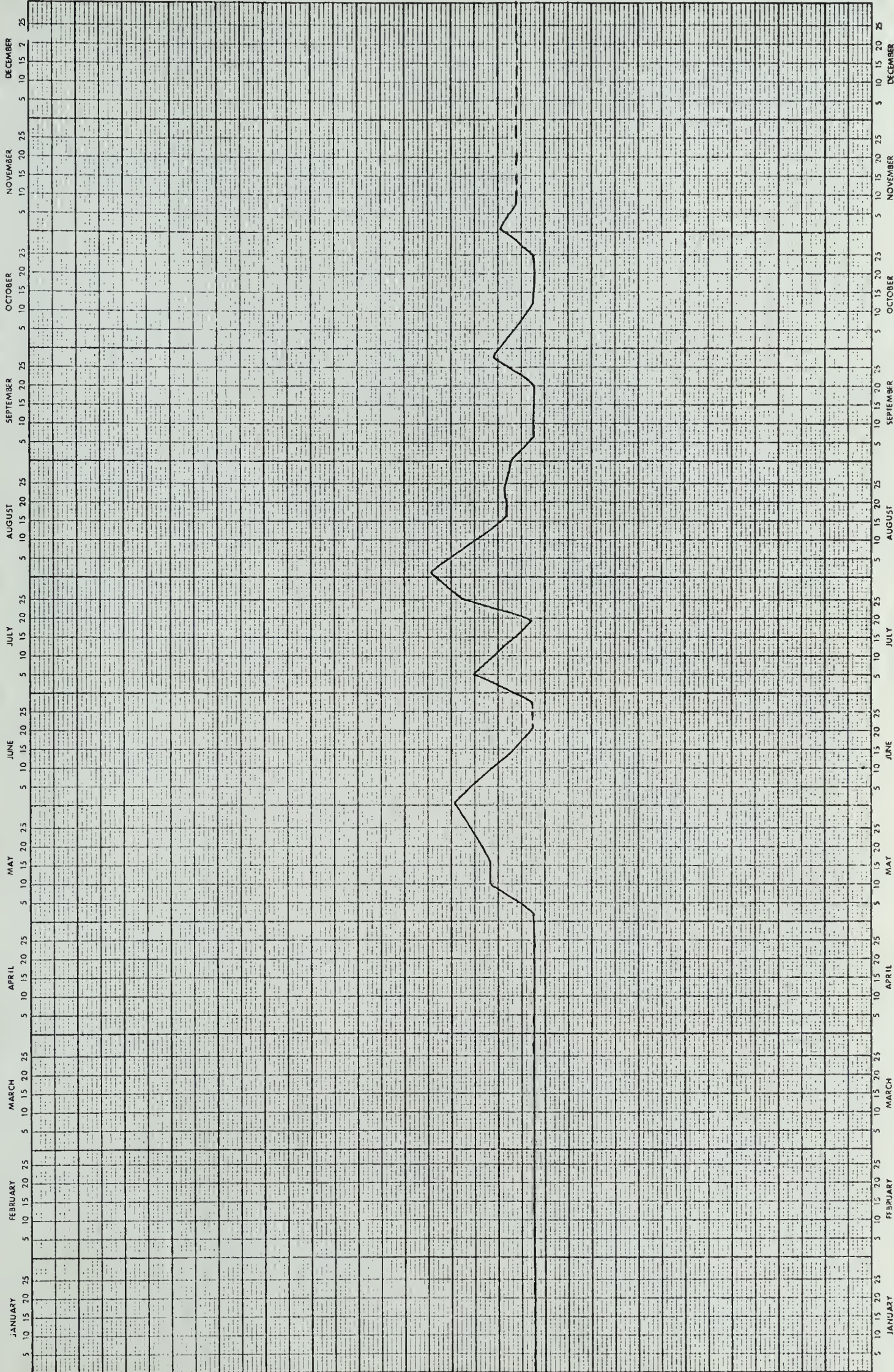
RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

for year ending 31 December 19 66

Station No N900 WT-SR24

Mean
Geod. Elev.

5888
5887
5886
5885
5884
5883
5882
5881
5880
5879
5878
5877

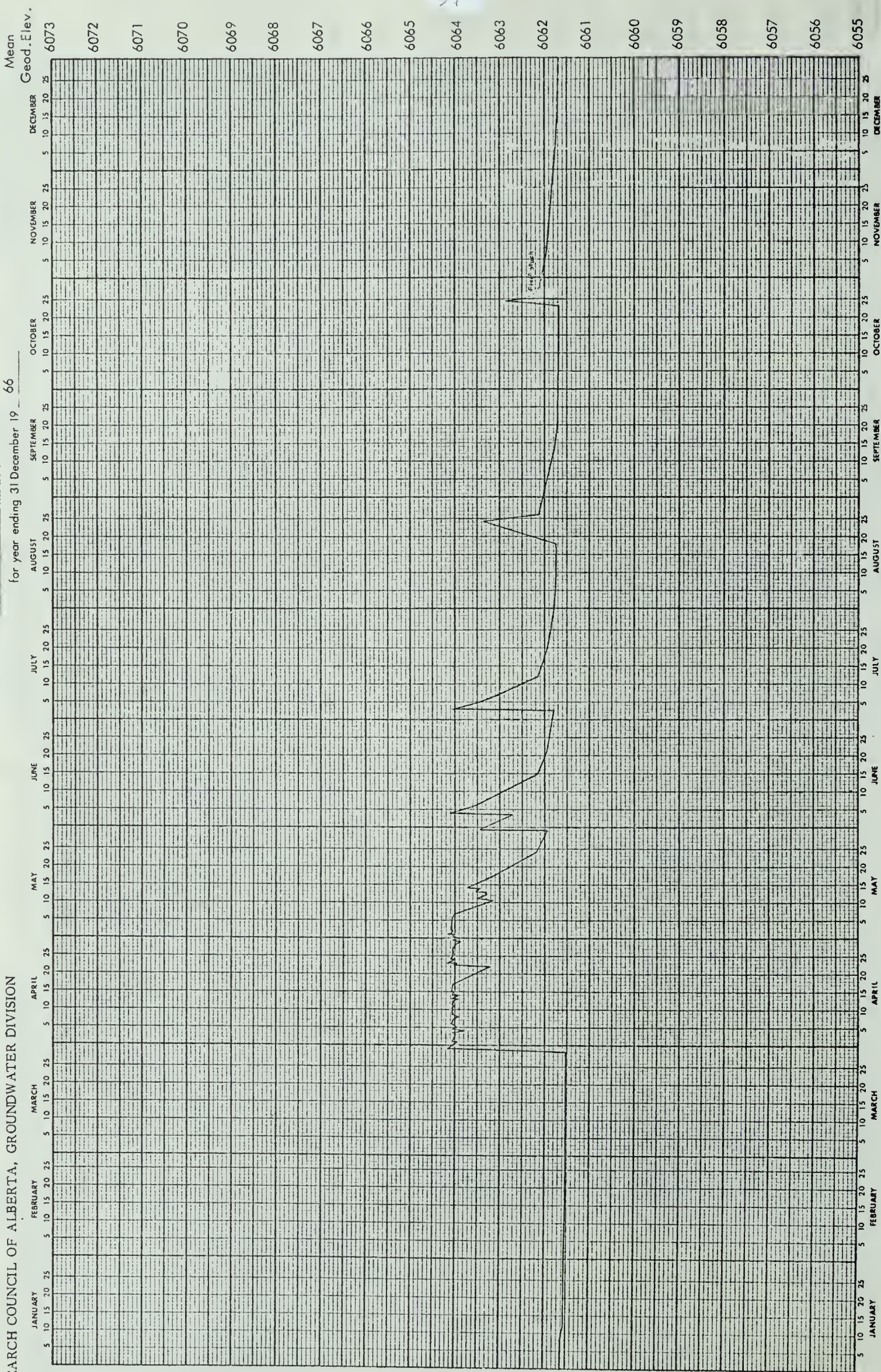


Plotted by _____ Checked by _____ Approved by _____ Date _____

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. N1080 WT-SR20

for year ending 31 December 19 66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION



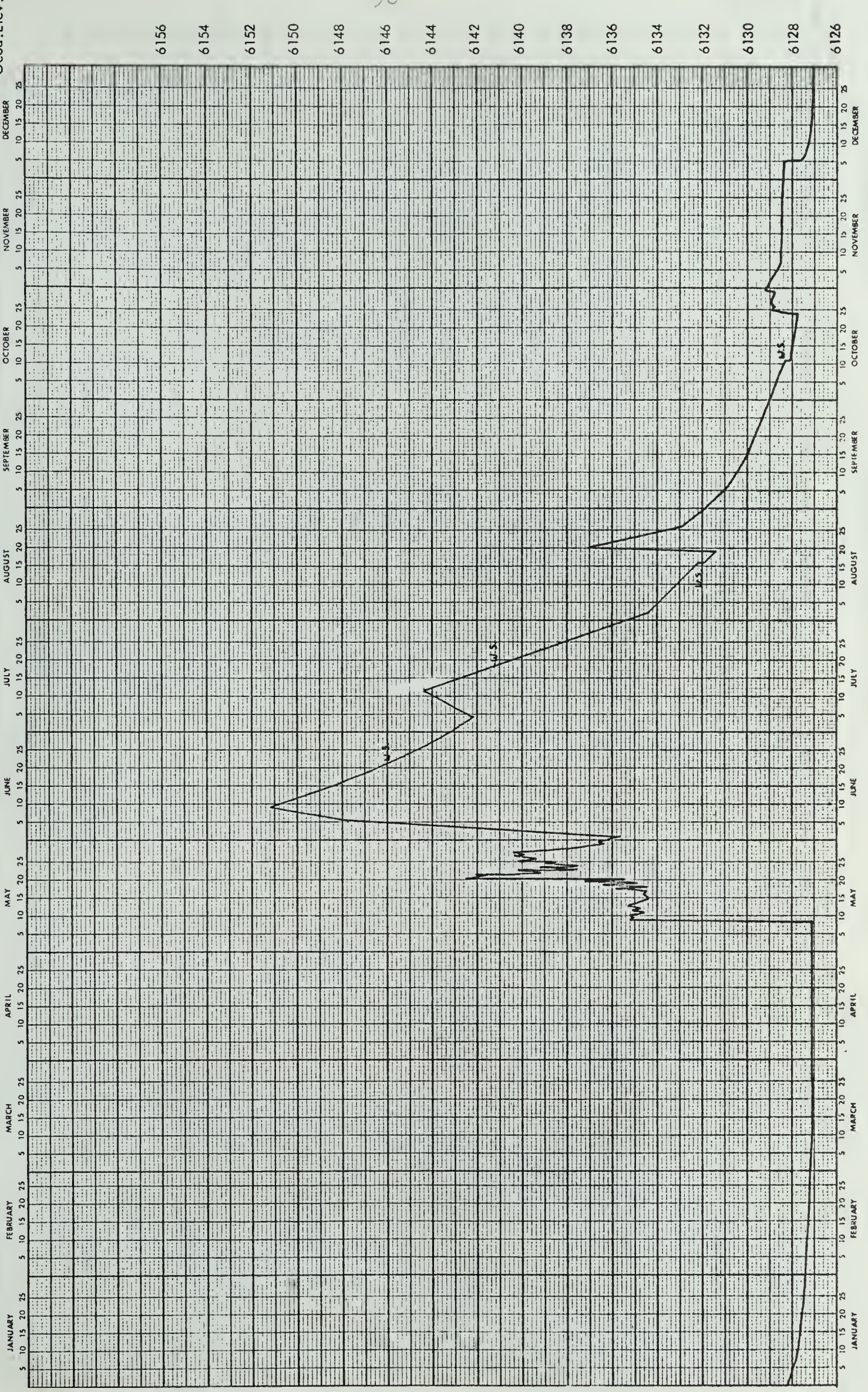
Plotted by _____ Checked by _____ Approved by _____ Date _____

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. S1170 WT-F47

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

Mean
Geod. Elev.

for year ending 31 December 19

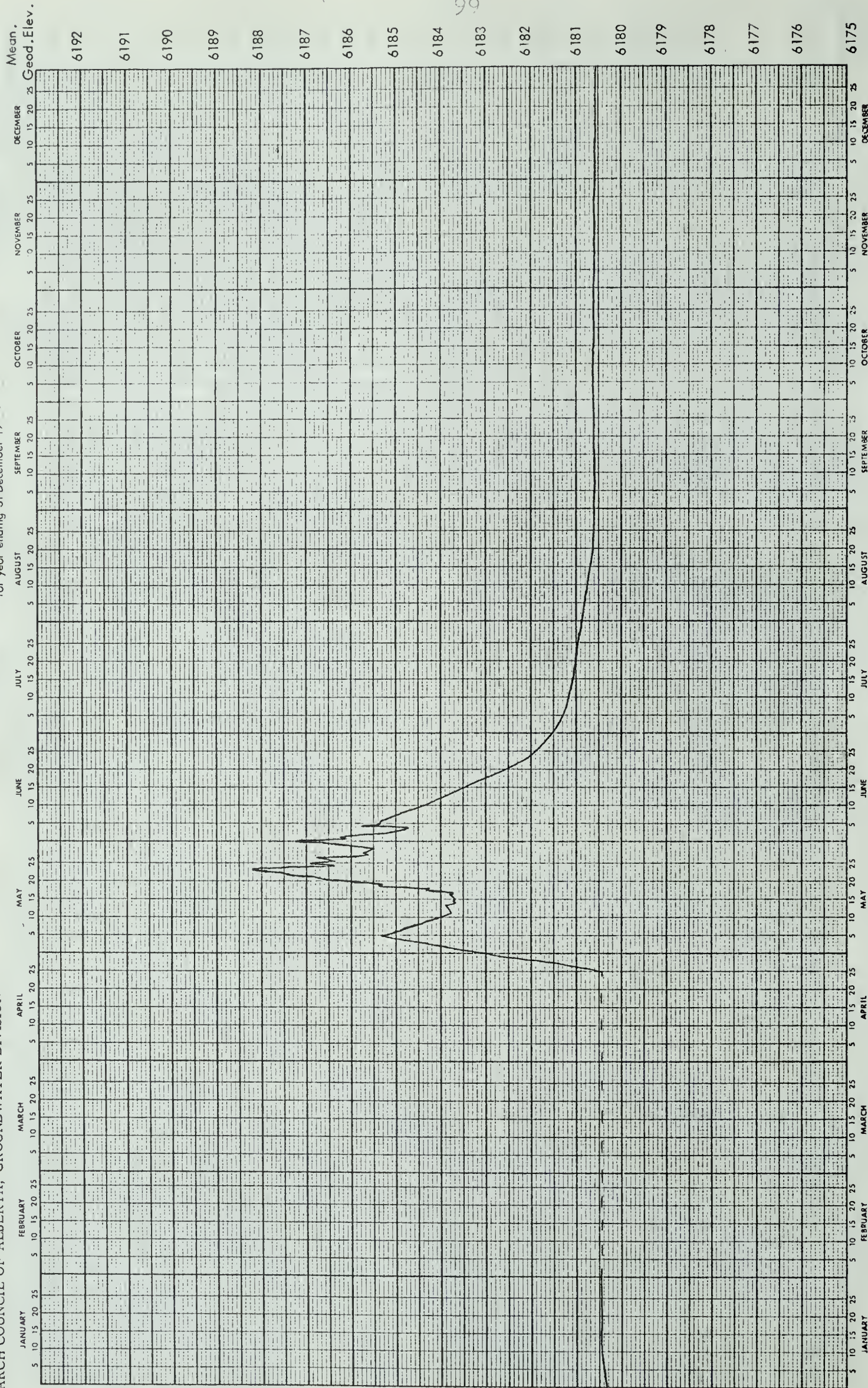


Plotted by _____ Checked by _____ Approved by _____ Date _____

Station No. N1200WT-SR22

HYDROGRAPH FOR MARMOT CREEK BASIN
for year ending 31 December 19 66

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION



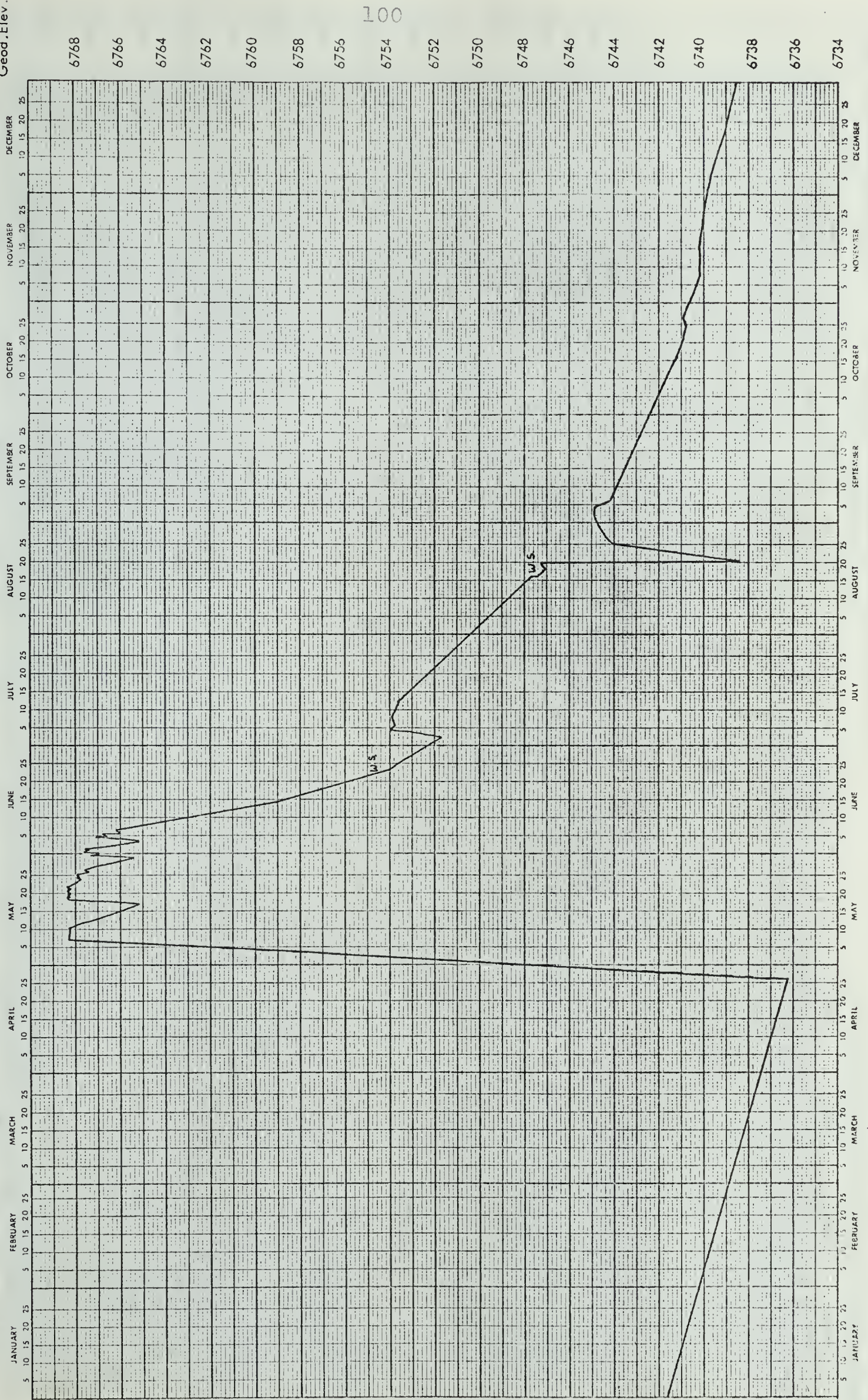
Plotted by _____ Checked by _____ Approved by _____ Date _____

HYDROGRAPH FOR MARMOT CREEK BASIN Water-table well Station No. N1770-WT-F38

RESEARCH COUNCIL OF ALBERTA, GROUNDWATER DIVISION

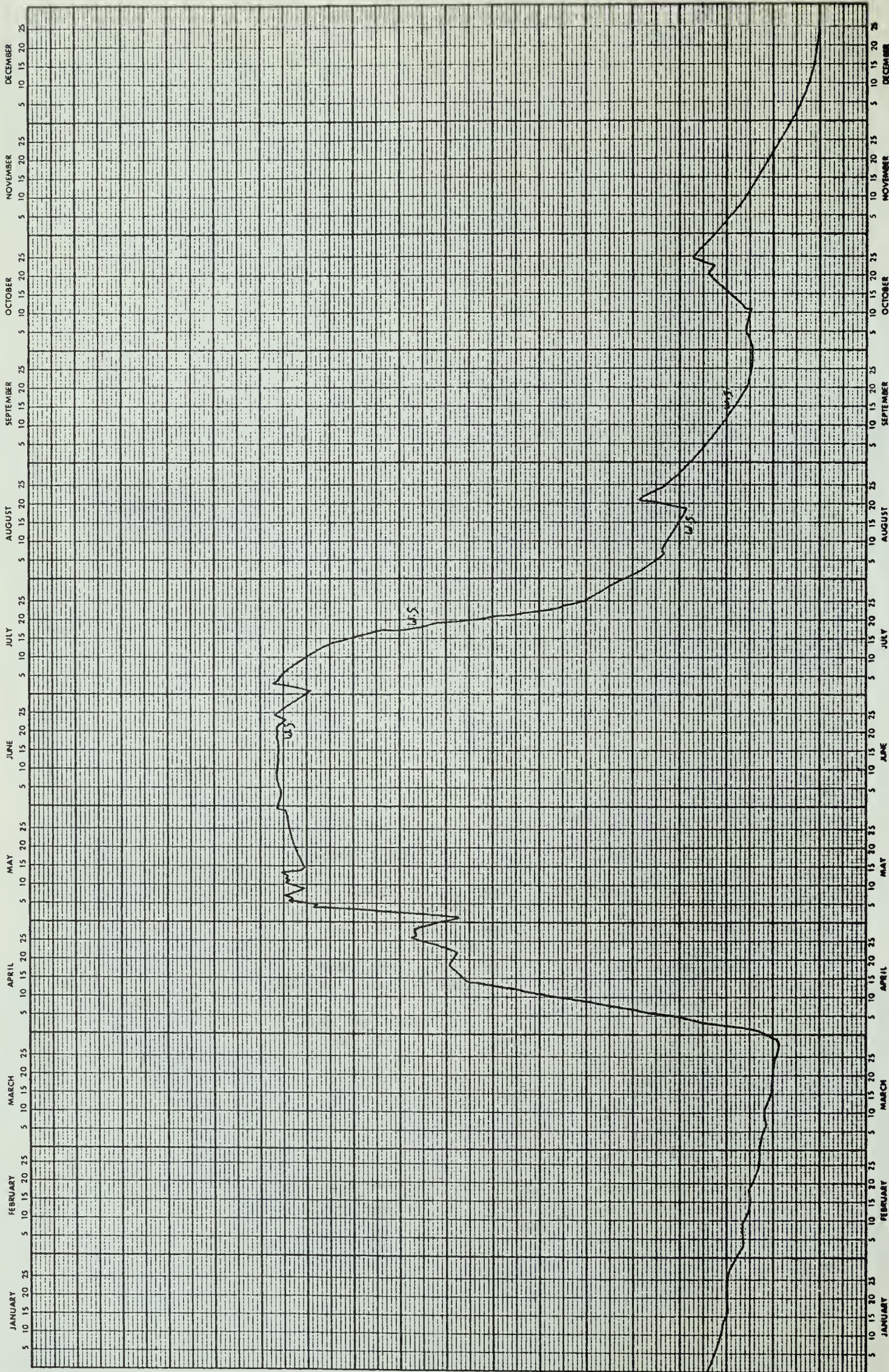
for year ending 31 December 19 66

Mean
Geod. Elev.



Plotted by _____ Checked by _____ Approved by _____ Date _____

5420
5418
5416
5414
5412
5410
5408
5406
5404
5402
5400
5398
5396
5394



Plotted by _____ Checked by _____ Approved by _____ Date _____

PLATE I

Surficial Deposits in the Marmot Creek Area

- Figure 1. Kananaskis Valley below the Marmot Creek basin, showing ice-contact and Postglacial deposits.
- Figure 2. Ice-contact deposit on the west wall of the Kananaskis Valley below Marmot Creek basin.
- Figure 3. Glaciofluvial deposit located on the west wall of Cabin Creek above Marmot Creek confluence.
- Figure 4. Groundwater seepage along Marmot Creek.
- Figure 5. Large block of Cadomin conglomerate.
- Figure 6. East-facing cirque of Mount Allan showing patterned ground on hummocky cirque moraine.

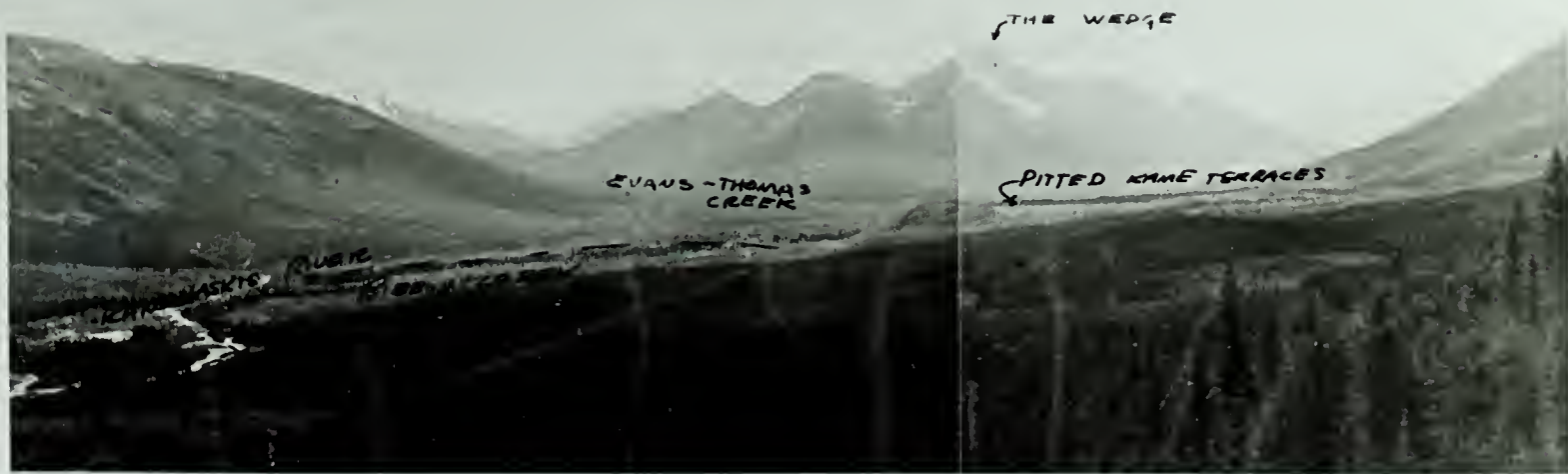


PLATE II

Mesozoic Rocks of the Marmot Creek Area

- Figure 1. Marmot Creek gorge cut into quartzites of the Rocky Mountain Group.
- Figure 2. Flaggy siltstones near the base of the Spray River Formation, Ribbon Creek Quarry.
- Figure 3. Massive silty dolomite at the top of the Spray River Formation on Ribbon Creek.
- Figure 4. Rock Creek member of the Fernie Formation, Ribbon Creek.
- Figure 5. Pigeon Creek member of the Fernie Formation, Ribbon Creek.
- Figure 6. Steep dipping concretionary member of Fernie Formation, Ribbon Creek.

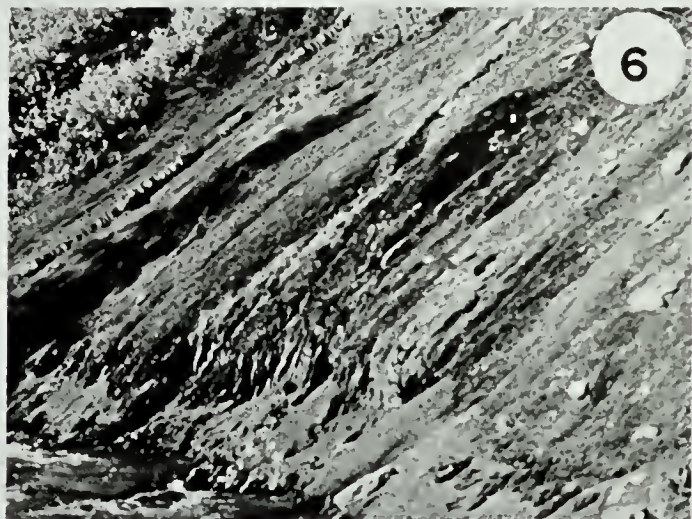
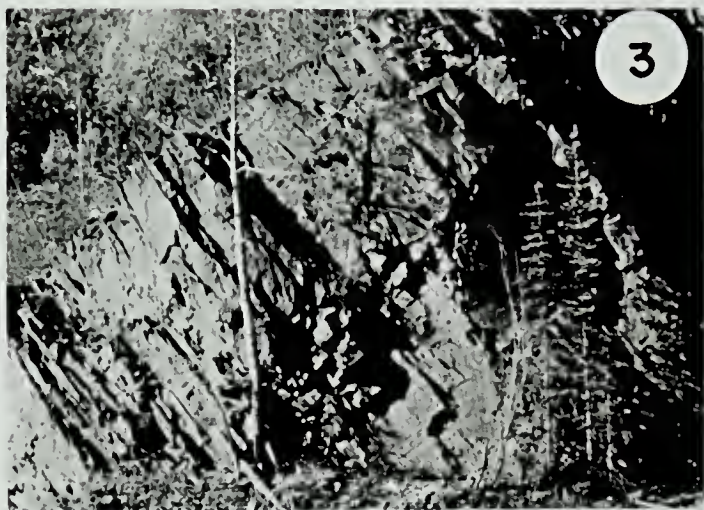
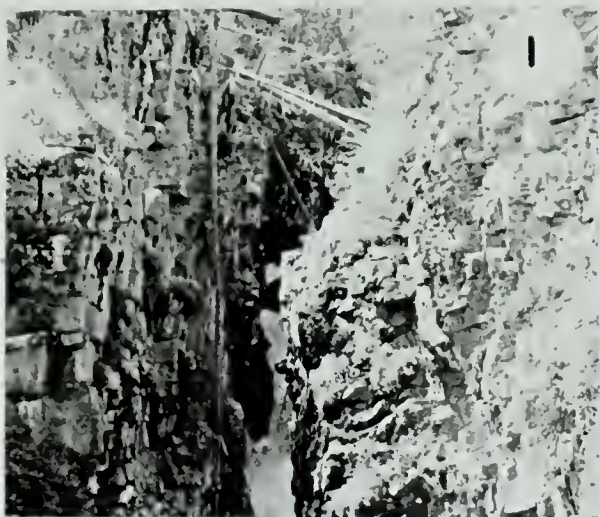


PLATE II.

PLATE III

Mesozoic Rocks on Mount Allan

- Figure 1. Mount Allan, looking northwest along overturned Mount Allan Syncline, Mount Rundle thrust block in background. (Photograph by the Forest Research Branch, Canada, Dept. Forestry).
- Figure 2. Upper sandstone member and Pocaterra Creek member of the Kootenay Formation. Cadomin conglomerate of basal Blairmore Formation on left peak. (Photograph by the Forest Research Branch, Canada, Dept. Forestry).
- Figure 3. Looking past the south ridge of Mount Allan Syncline into the U-shaped valley of Ribbon Creek. (Photograph by the Forest Research Branch, Canada, Dept. Forestry).
- Figure 4. Small cirque at base of upper sandstone member of Kootenay Formation northeast of Mount Allan. (Photograph by the Forest Research Branch, Canada, Dept. Forestry).
- Figure 5. Old Kananaskis coal mine on southeast ridge of Mount Allan.



PLATE III.

PLATE IV

Hydrologic Instrumentation in the Marmot Creek Area

- Figure 1. V-notch weir at Marmot Creek Main Stem, Marmot Creek basin.
- Figure 2. V-notch weir at Middle Fork Creek, Marmot Creek basin.
- Figure 3. H-flume set in Cabin Creek channel, Marmot Creek basin.
- Figure 4. Class A meteorological site at Con. 5, Marmot Creek basin.
- Figure 5. Groundwater recorder on a water-table observation well, Marmot Creek basin.
- Figure 6. Crew setting well screen with rotary rig in Marmot Creek basin.

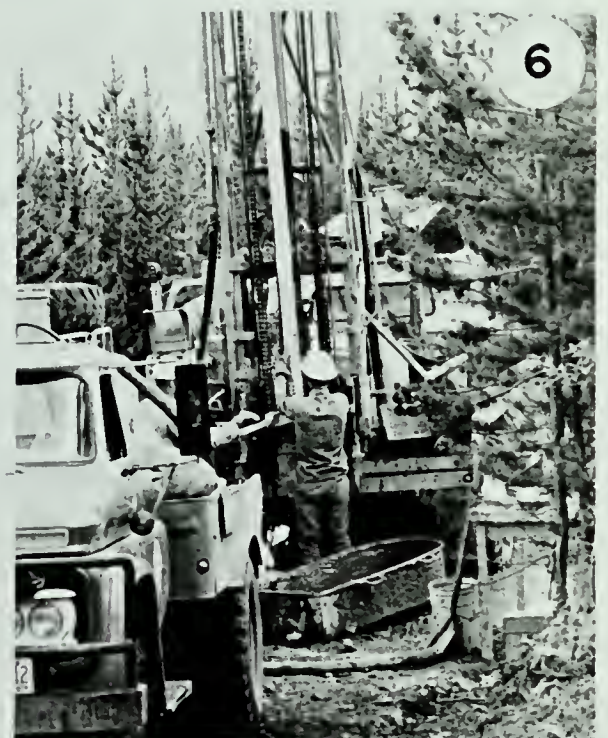
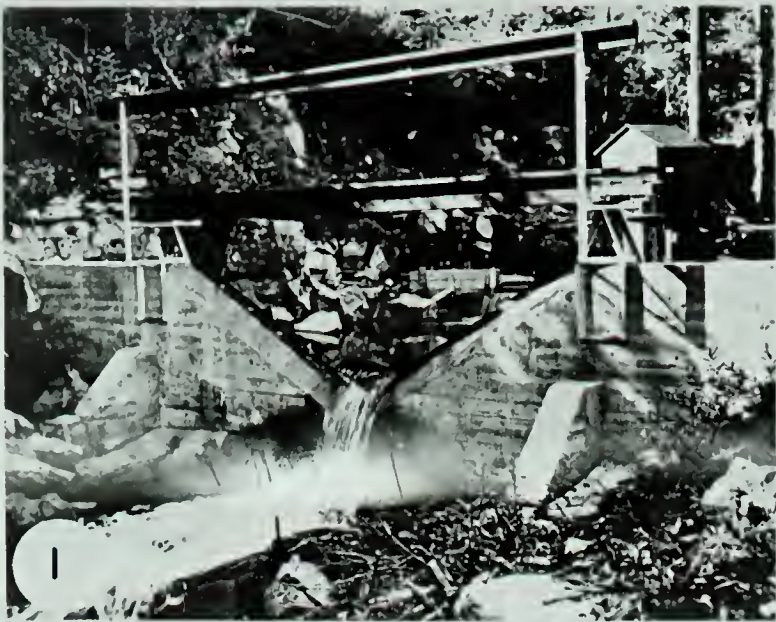


PLATE IV.

PLATE V

Thin Sections of Mesozoic Rocks in the Marmot Creek Area

- Figure 1. Thin section: Quartzite of the Rocky Mountain Group x 160. No intergranular porosity.
- Figure 2. Thin section: Spray River Formation x 400. No intergranular porosity.
- Figure 3. Thin section: Pigeon Creek member x 160. No intergranular porosity.
- Figure 4. Thin section: Passage Beds, Fernie Formation x 160. No intergranular porosity.
- Figure 5. Thin section: Basal Kootenay sandstone x 160. No intergranular porosity.
- Figure 6. Thin section: Kootenay sandstone x 160. No intergranular porosity.

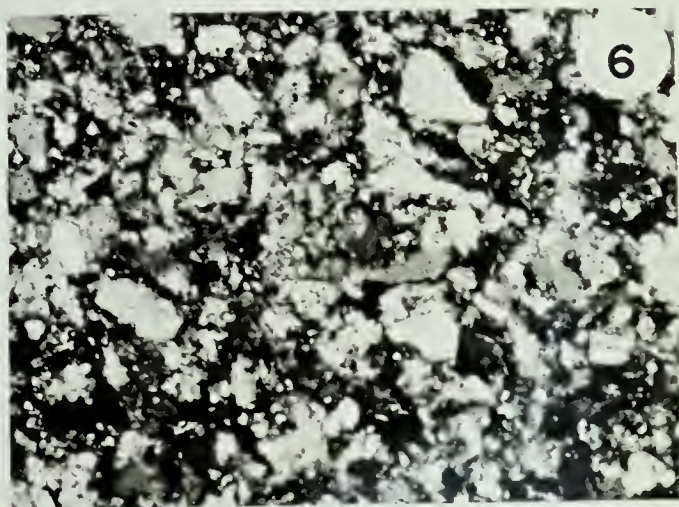
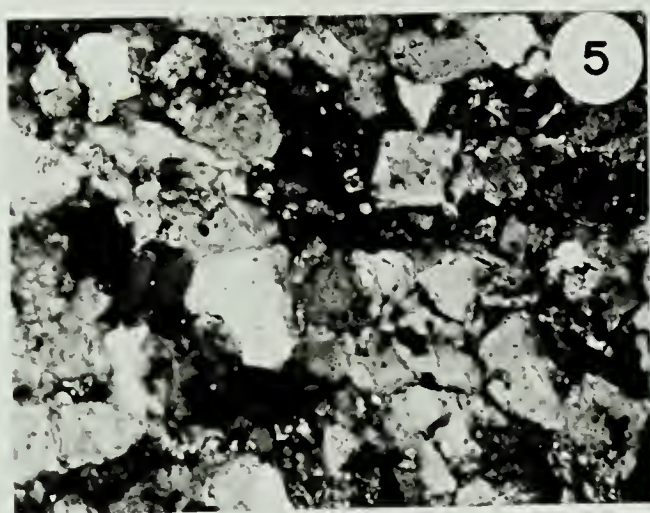
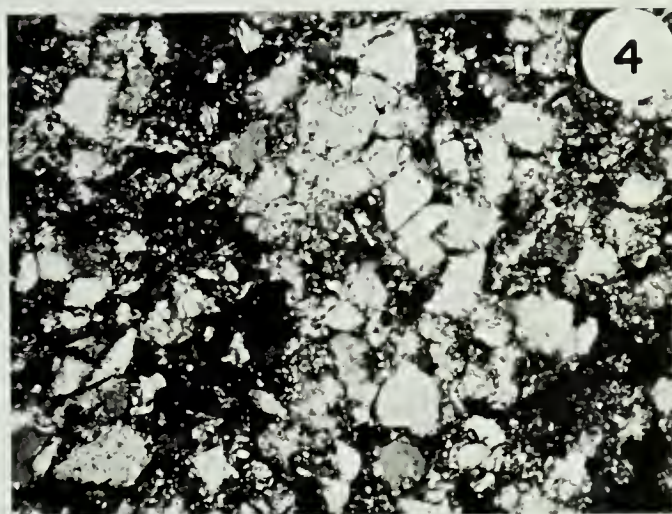
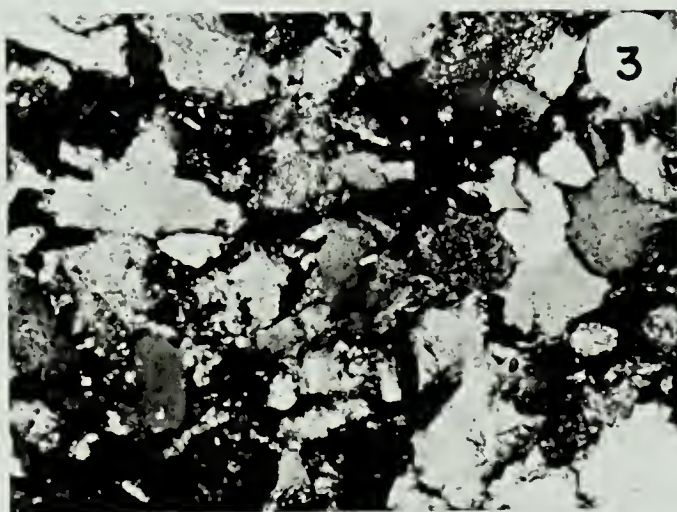
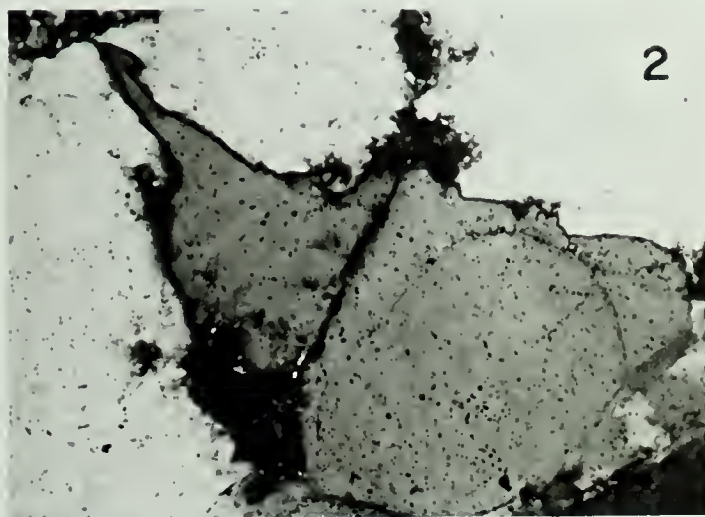
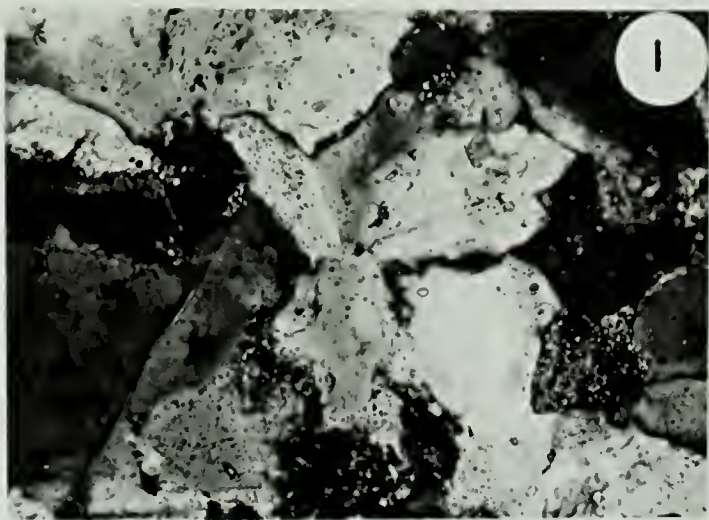
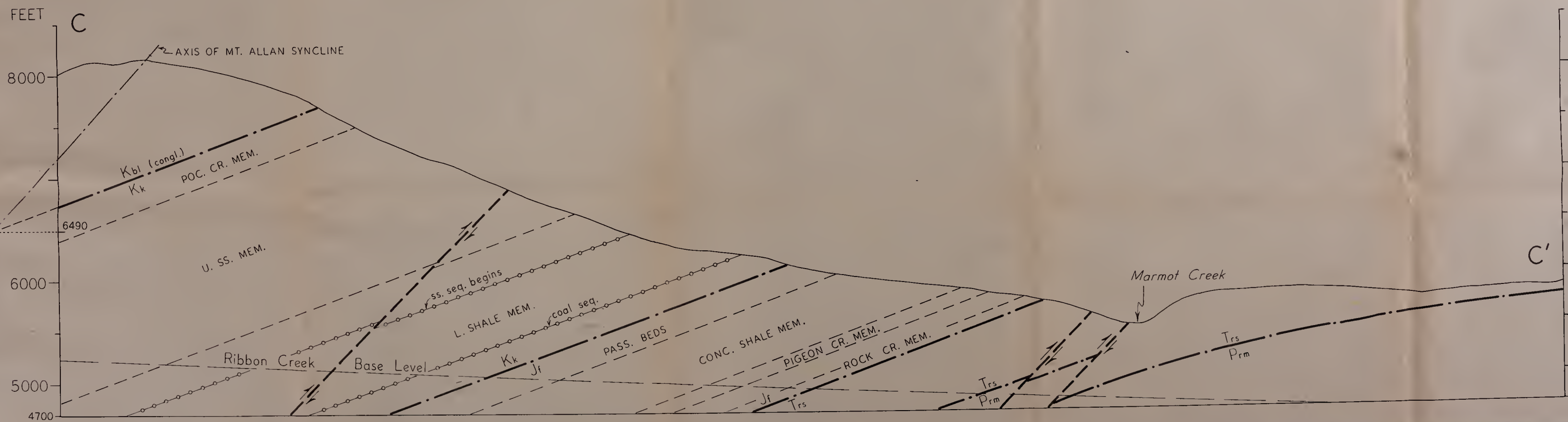
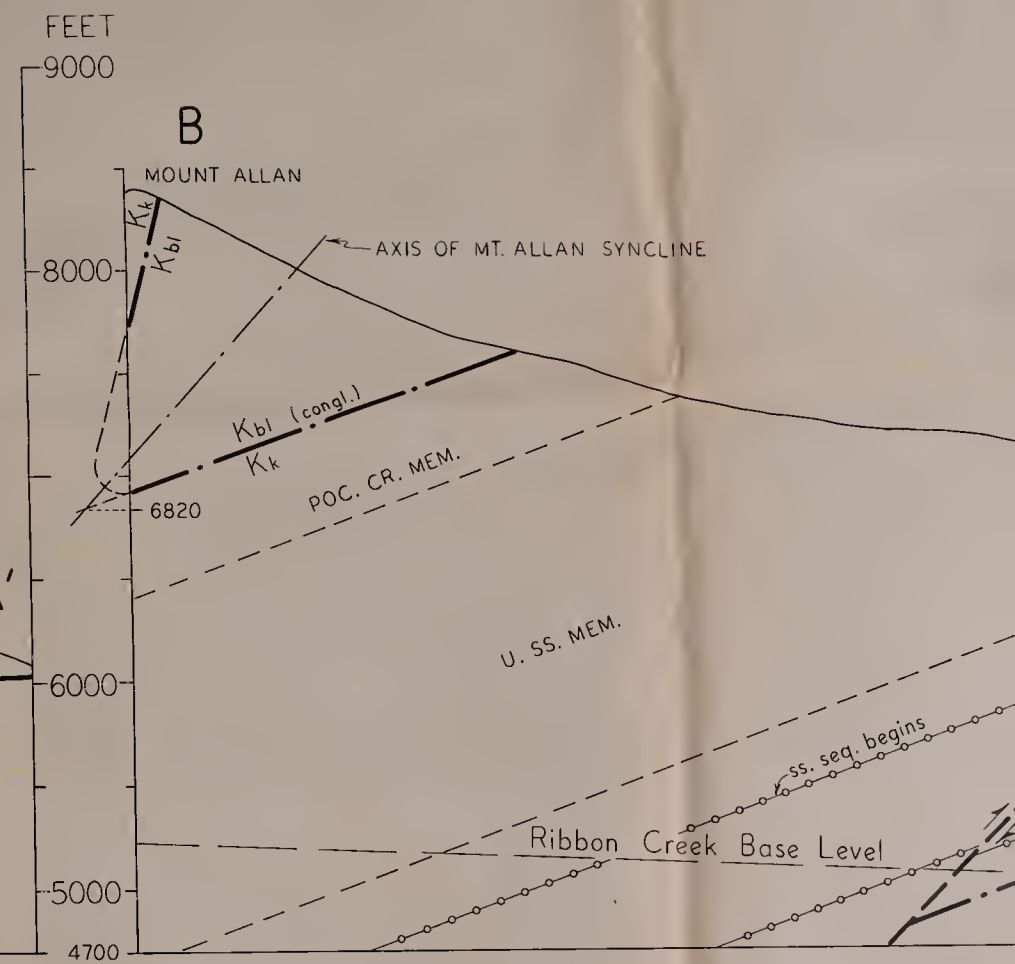
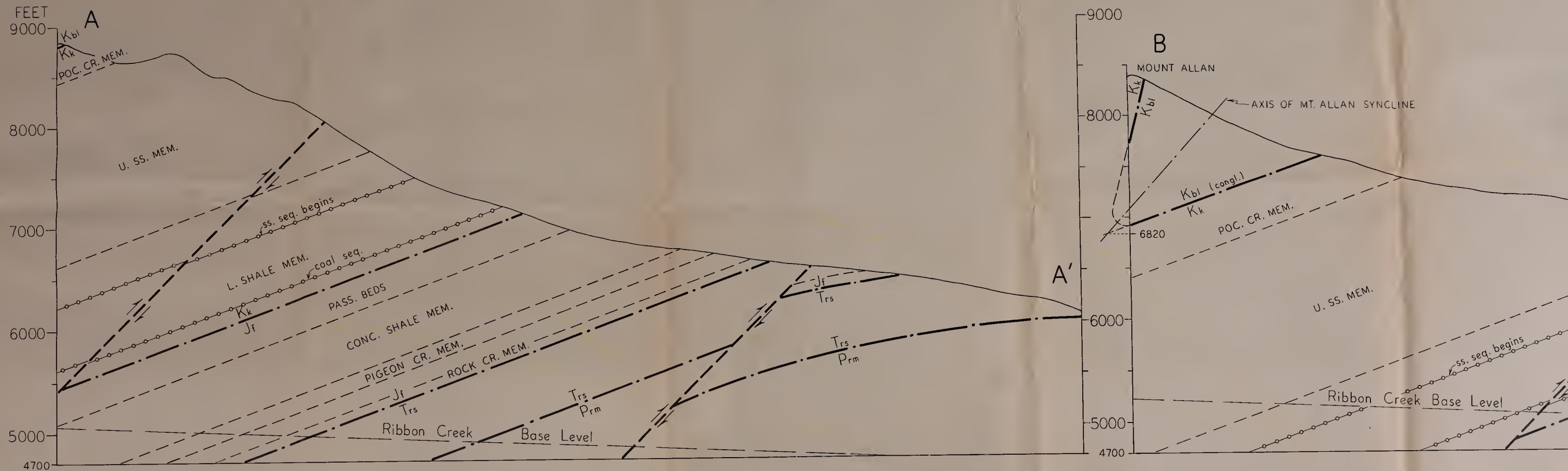
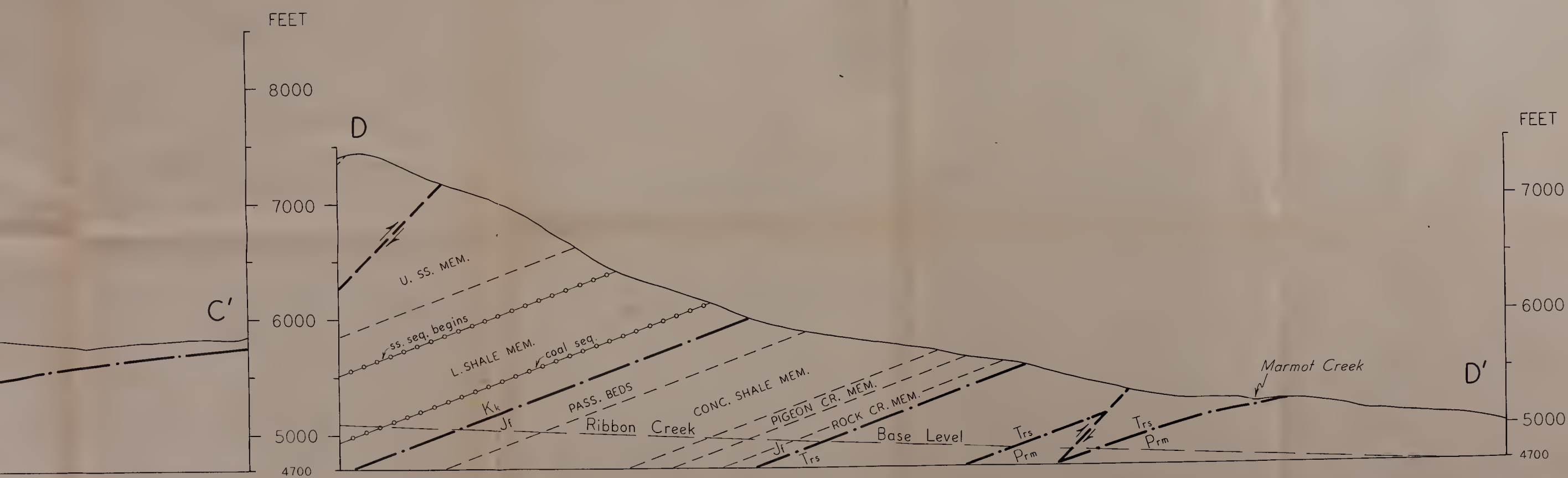
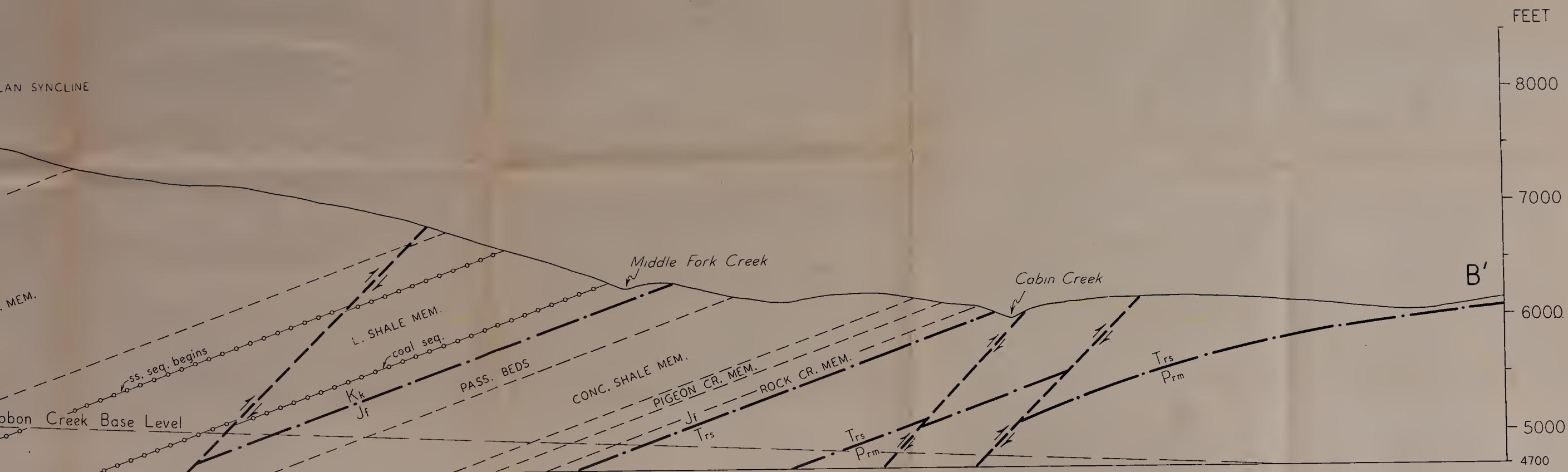


PLATE V.



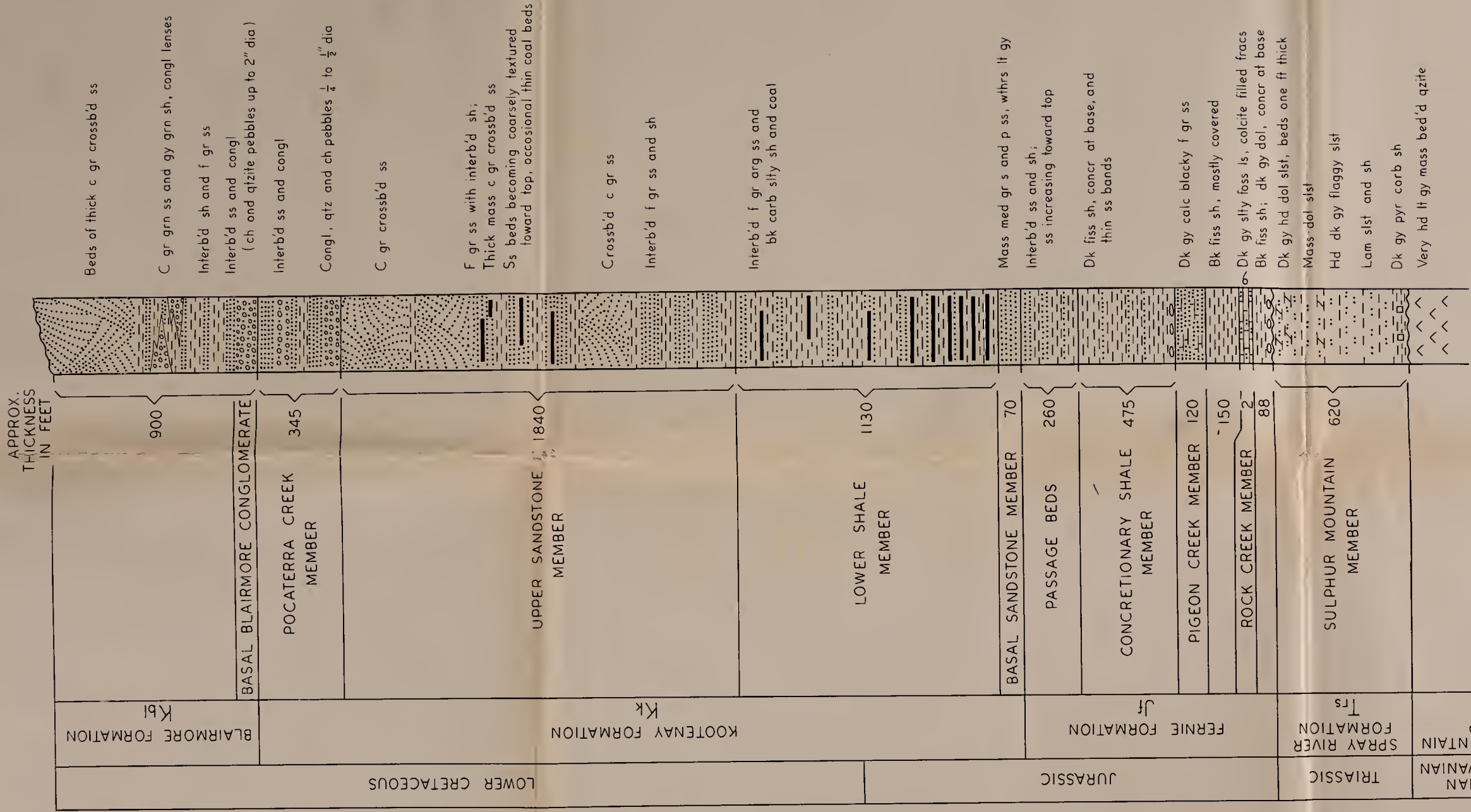


STRUCTURE SECTIONS

Horizontal and Vertical Scales same as Scale of Map

GENERALIZED STRATIGRAPHIC COLUMN, MT. ALLAN AREA

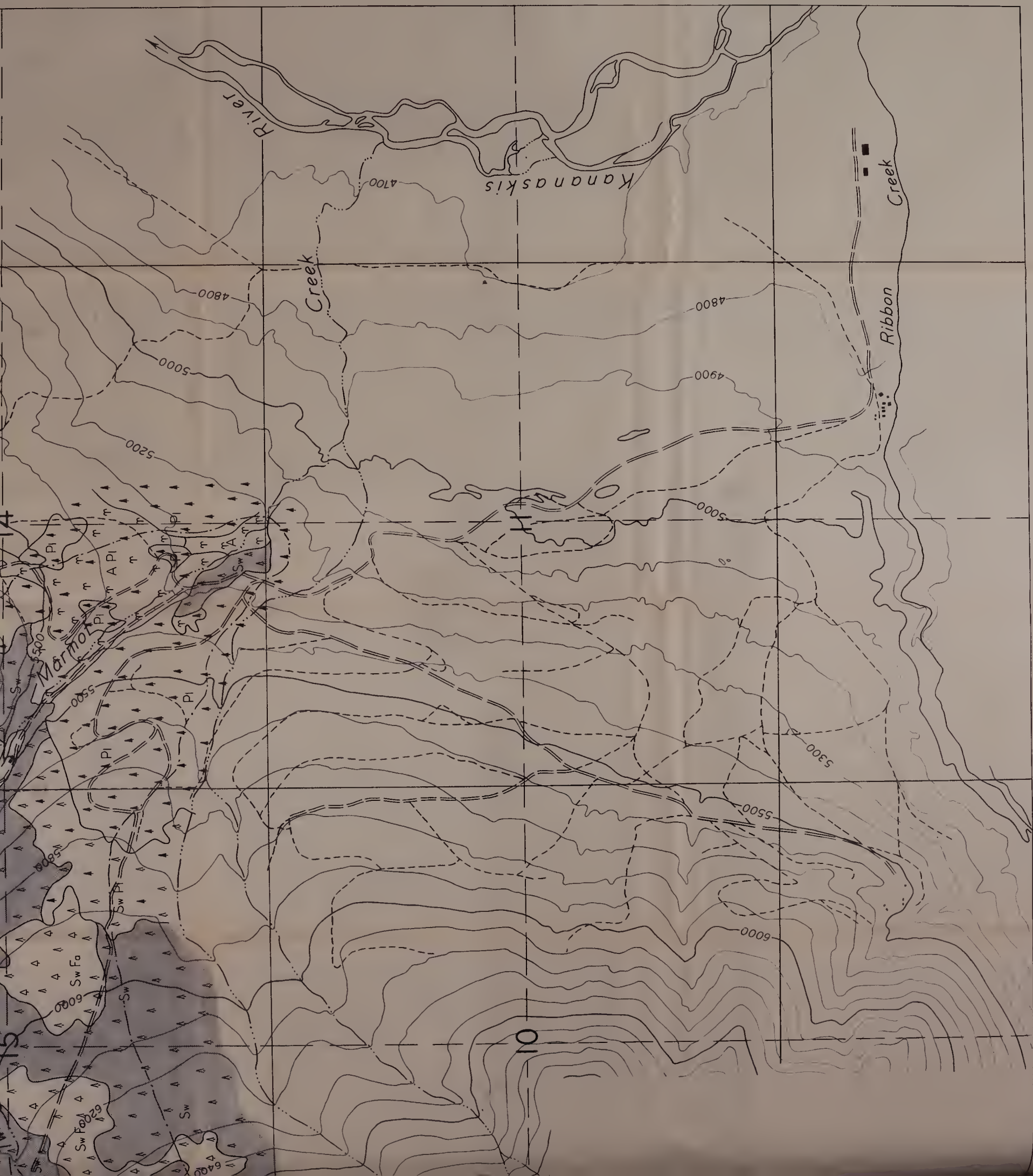
Crockford, 1949
Author's personal observation, 1964

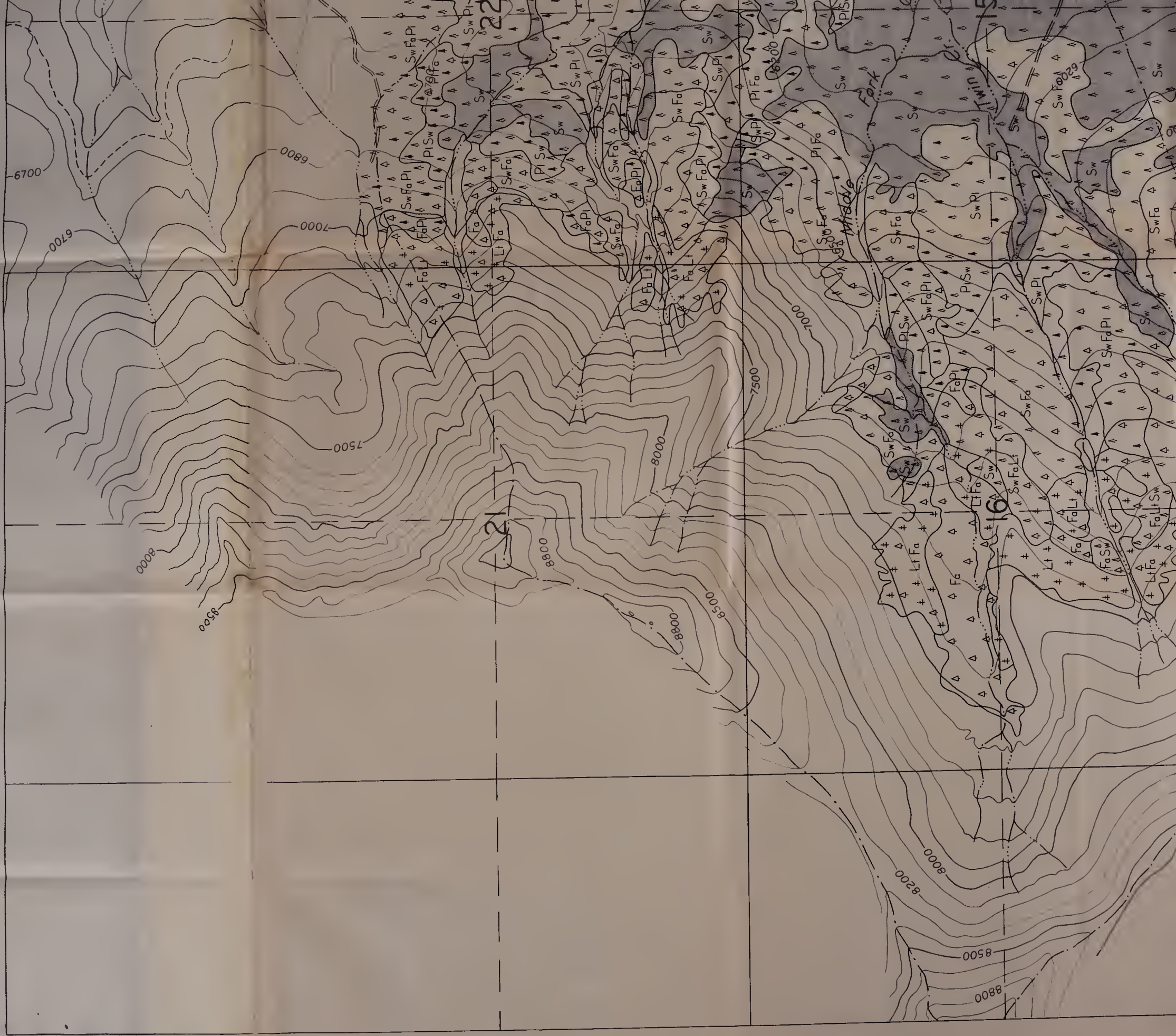


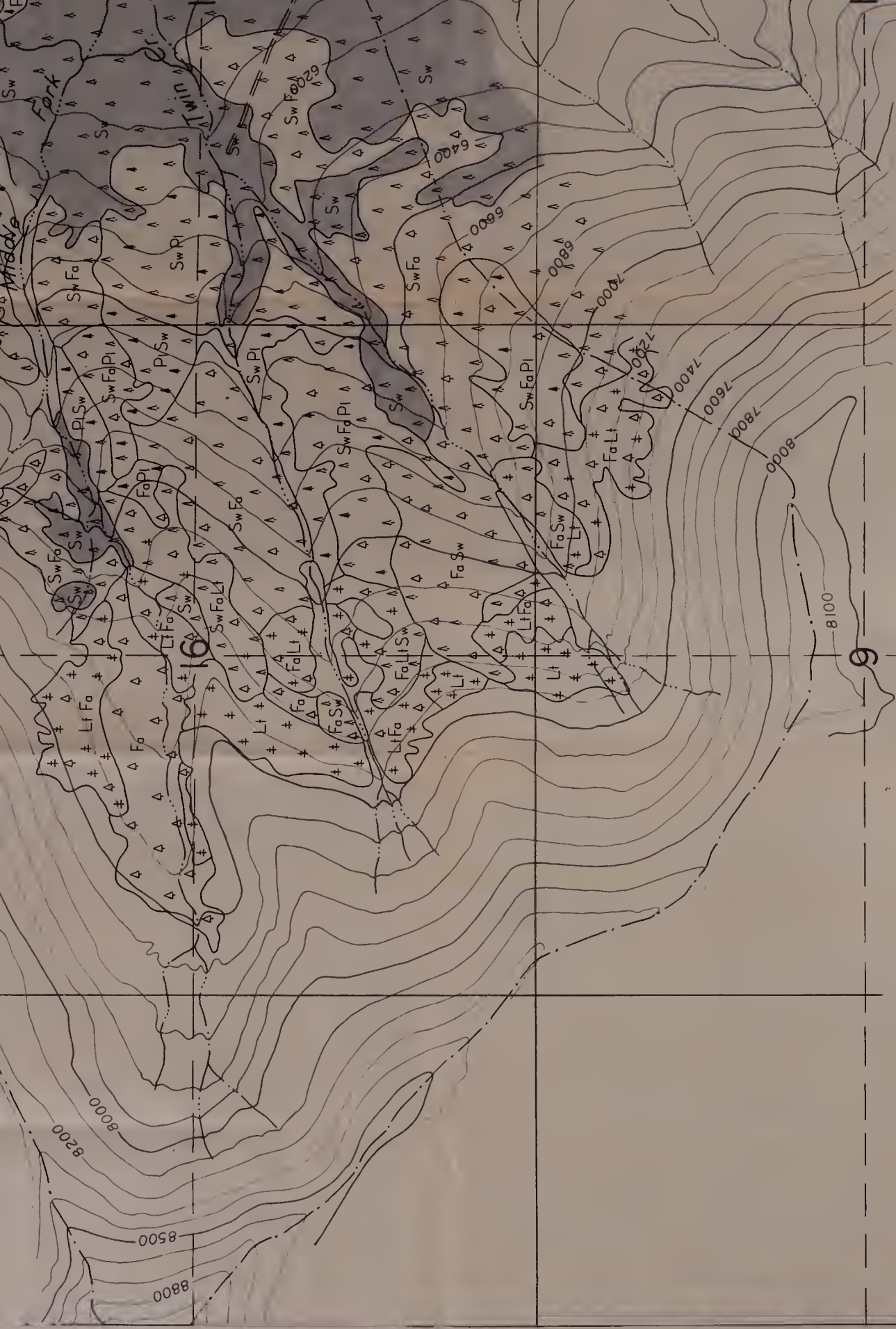
LEGEND

	Conglomerate
	Sandstone
	Sandstone, crossbedded
	Siltstone
	Shale
	Limestone
	Quartzite
	Coal
	Concretion
	Calcareous
	Dolomitic
	Pyritic
	Fossils





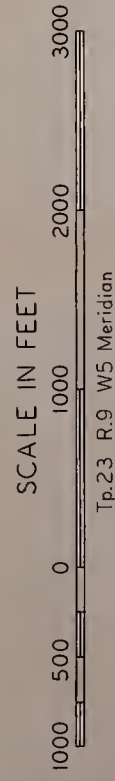




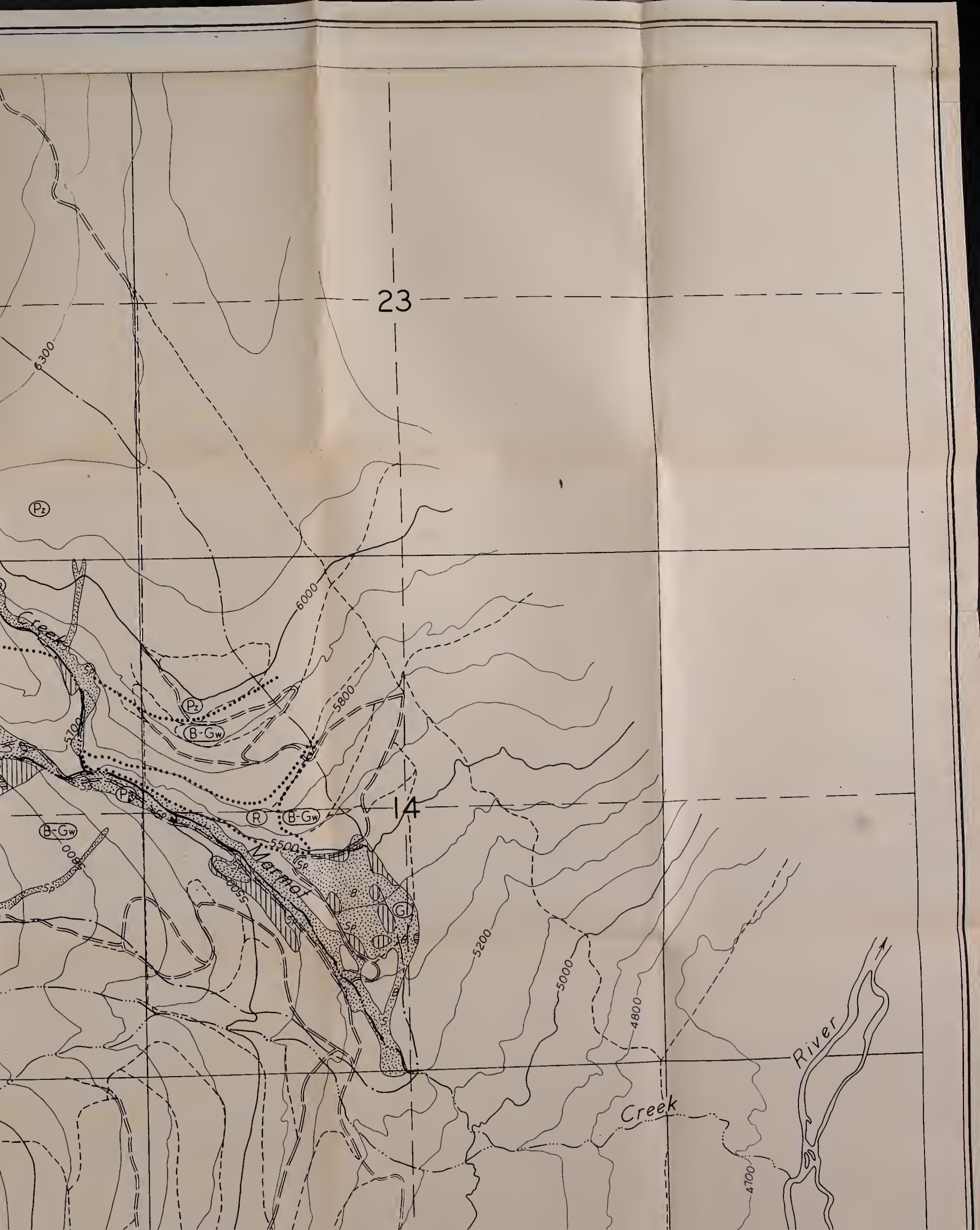
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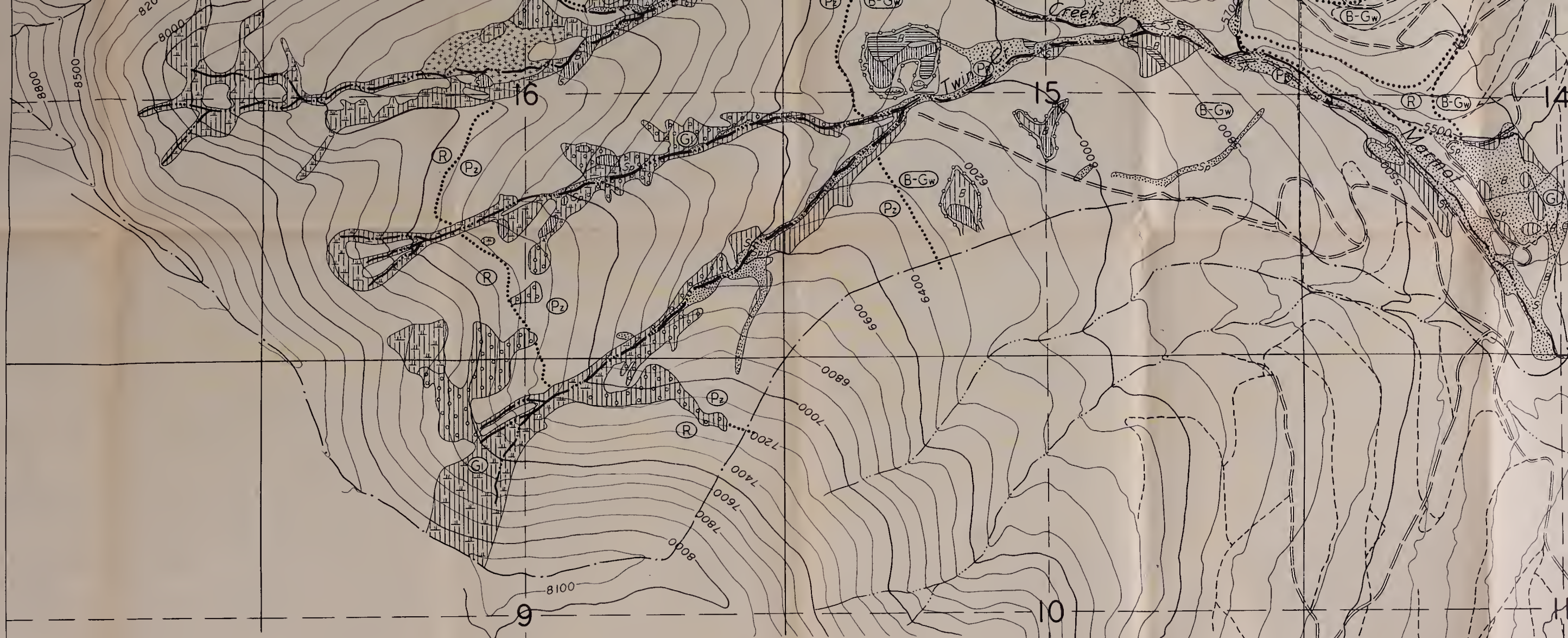
- Alpine Fir Fa ▲▲▲
- Larch Lt +++
- Aspen A TTT
- White Spruce Sw ^^^
- Lodgepole Pine Pl ↑↑↑
- Basin boundary (approx.) - - -

NOTE: Generalized from a detailed map prepared by the Alberta Forest Service from aerial photographs taken in 1963 and redrafted by the Calgary Regional Laboratory of the Department of Forestry, 1965.









LEGEND

SEEPAGE VARIETIES OF PLANT COVER *

- Seepage variants
- Vaccinium scoparium
- Equisetum
- Carex
- Sphagnum-ledum
- Salix
- Moist herb meadow

GROUNDWATER DISCHARGE FEATURES

- Boggy area where seepage is ponded B
- Groundwater seeps, mudflows Sp
- Spring discharging groundwater at the surface S
- Perennial stream or surface drain in the groundwater reservoir ..

GENERAL SOIL TYPES **

- Regosol soils and bedrock (R)
- Podzol soils (Pz)
- Alpine black soils (Ab)
- Organic soils area (B-Gw)
- Brunozolic grey wooded soils and some Bisequa (PR)
- Peaty Regosol soils (GI)
- Local Gleysols (GI)

- Boundary of soils area
- Basin boundary (approx.)

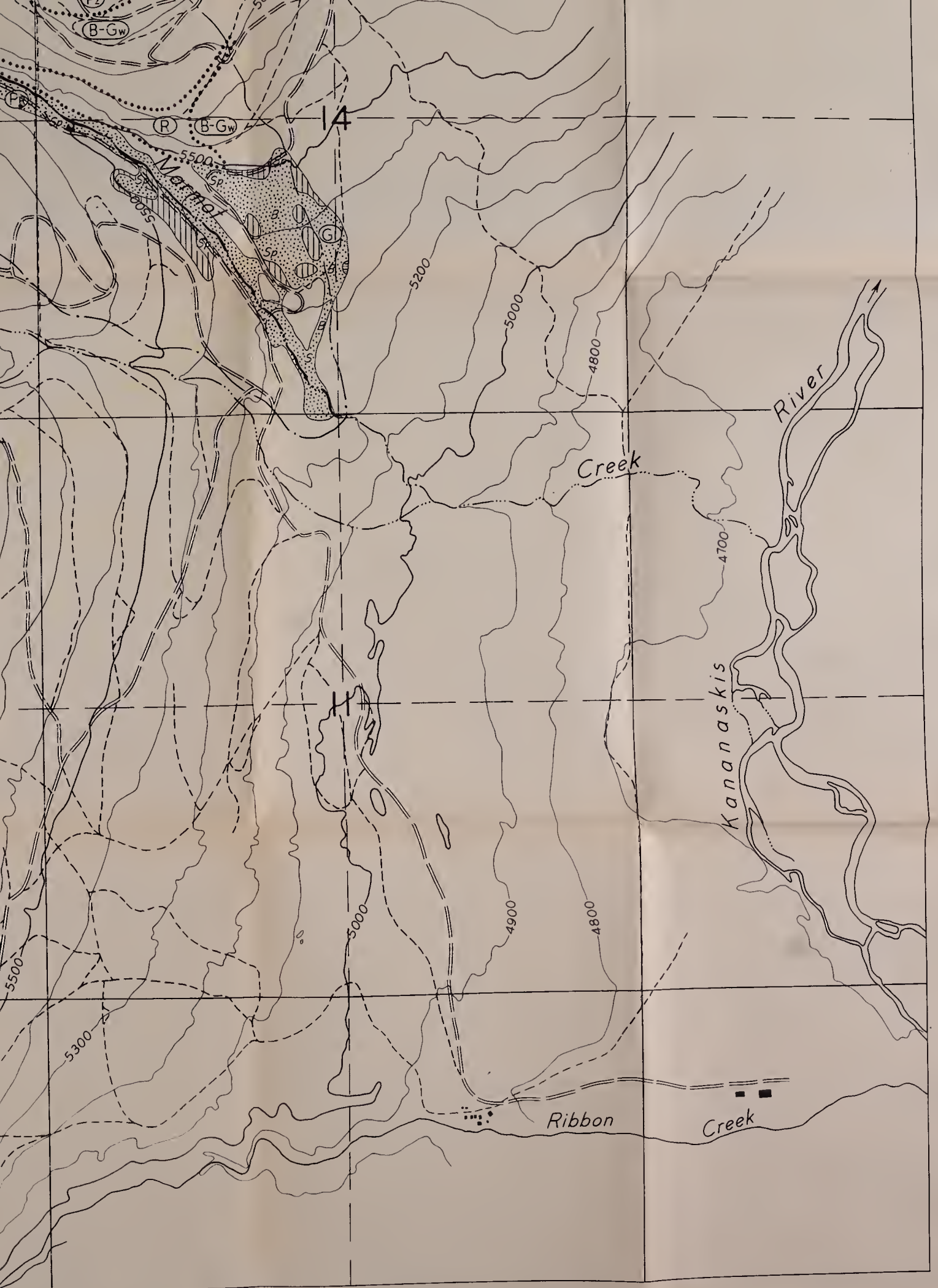
* From a forest cover map compiled and drawn by Dr. R.T. Ogilvie, Dept. of Forestry, Canada, 1963.

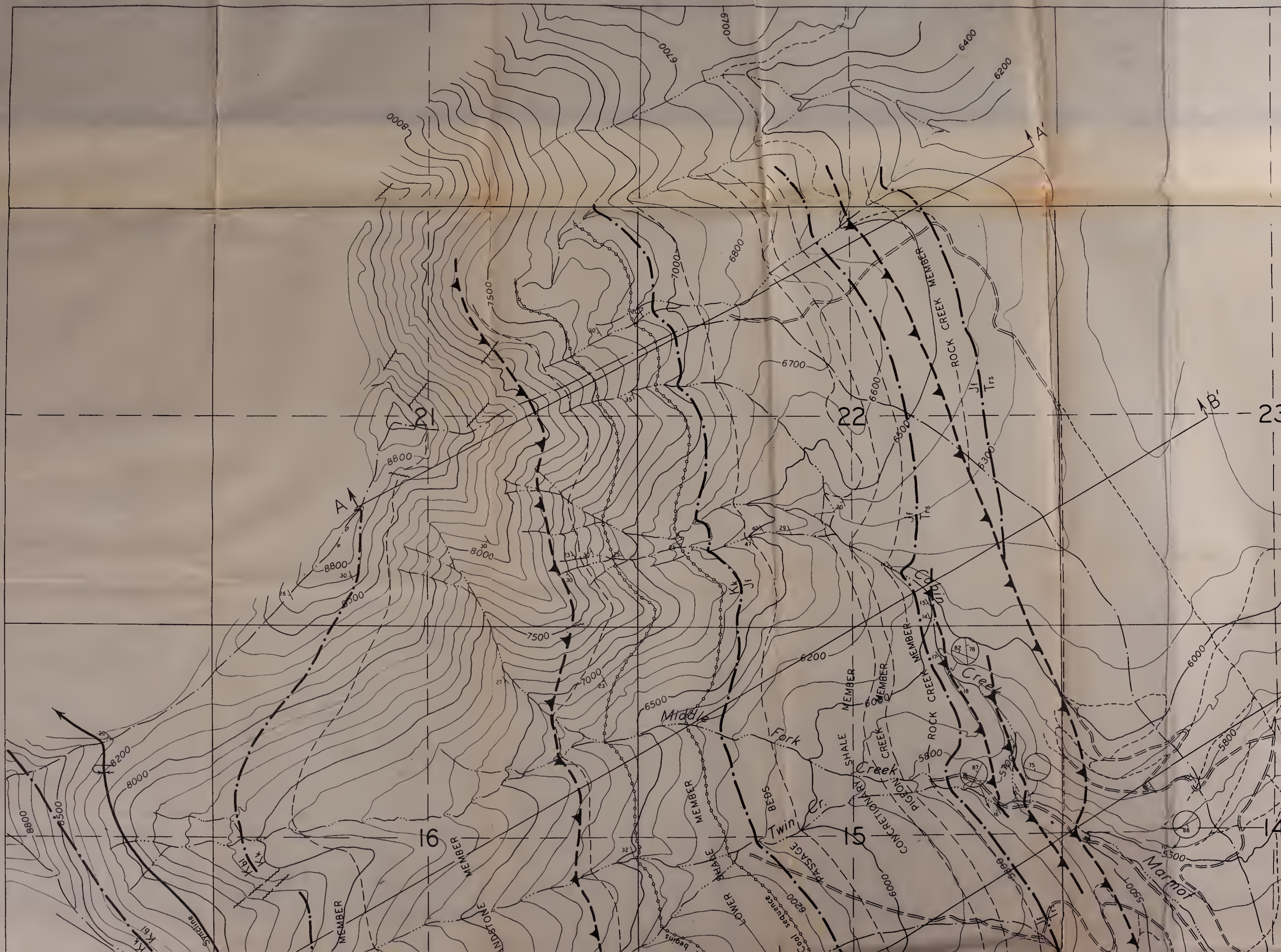
** From a reconnaissance soil survey map by the Alberta Soils Survey, 1963.

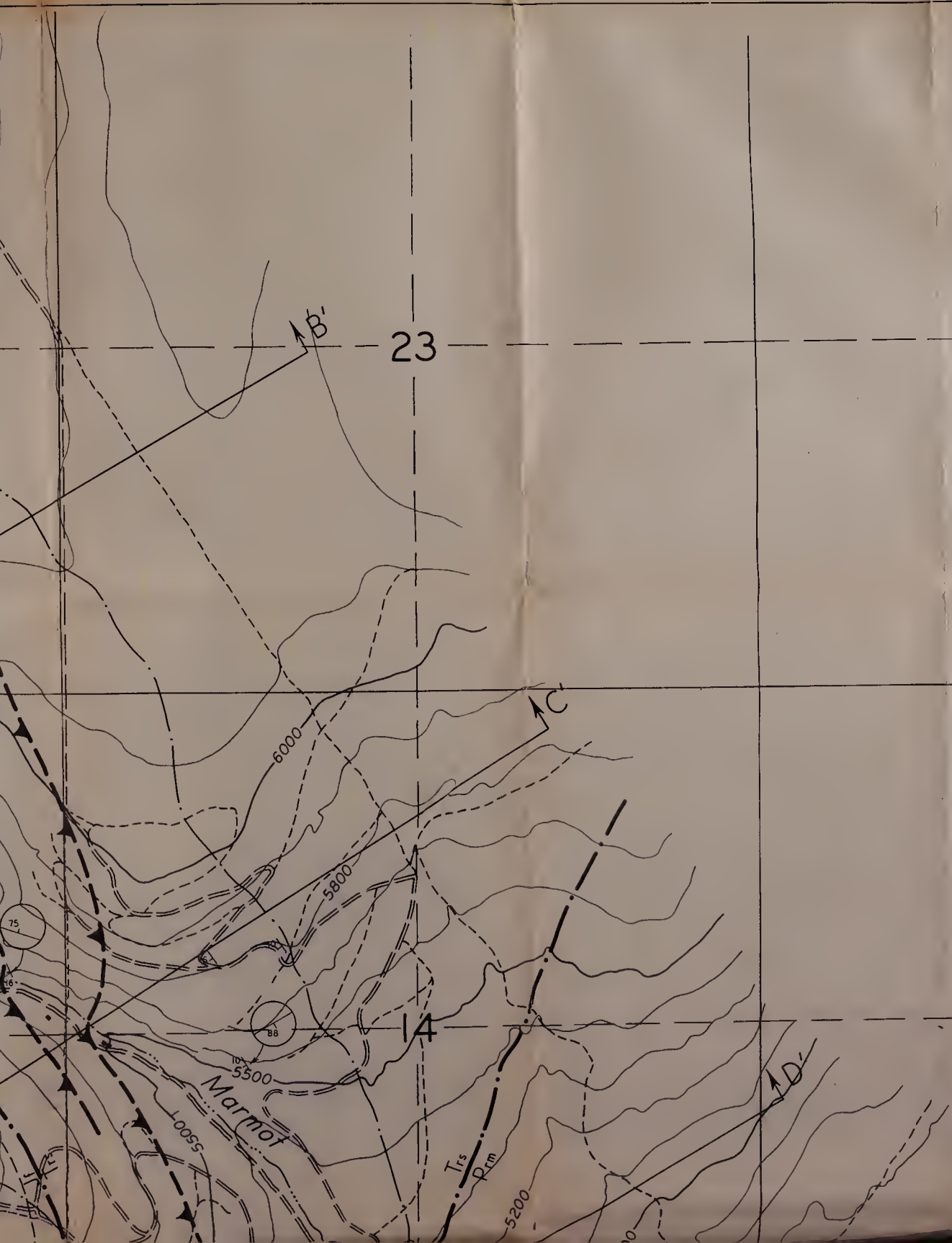
SCALE IN FEET

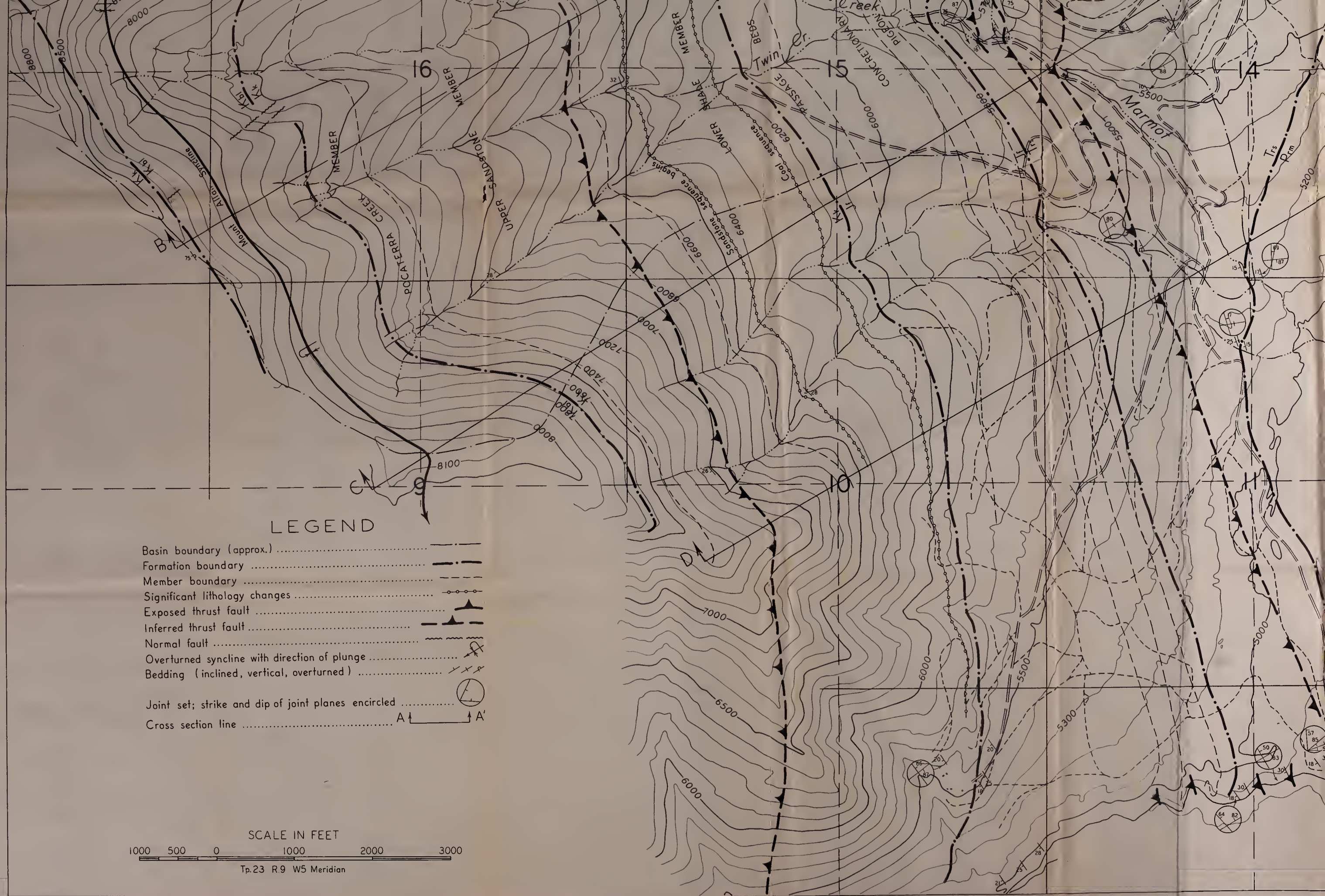
1000 500 0 1000 2000 3000

Tp.23 R.9 W5 Meridian



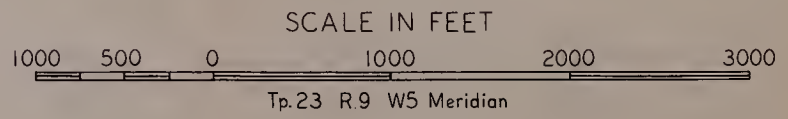


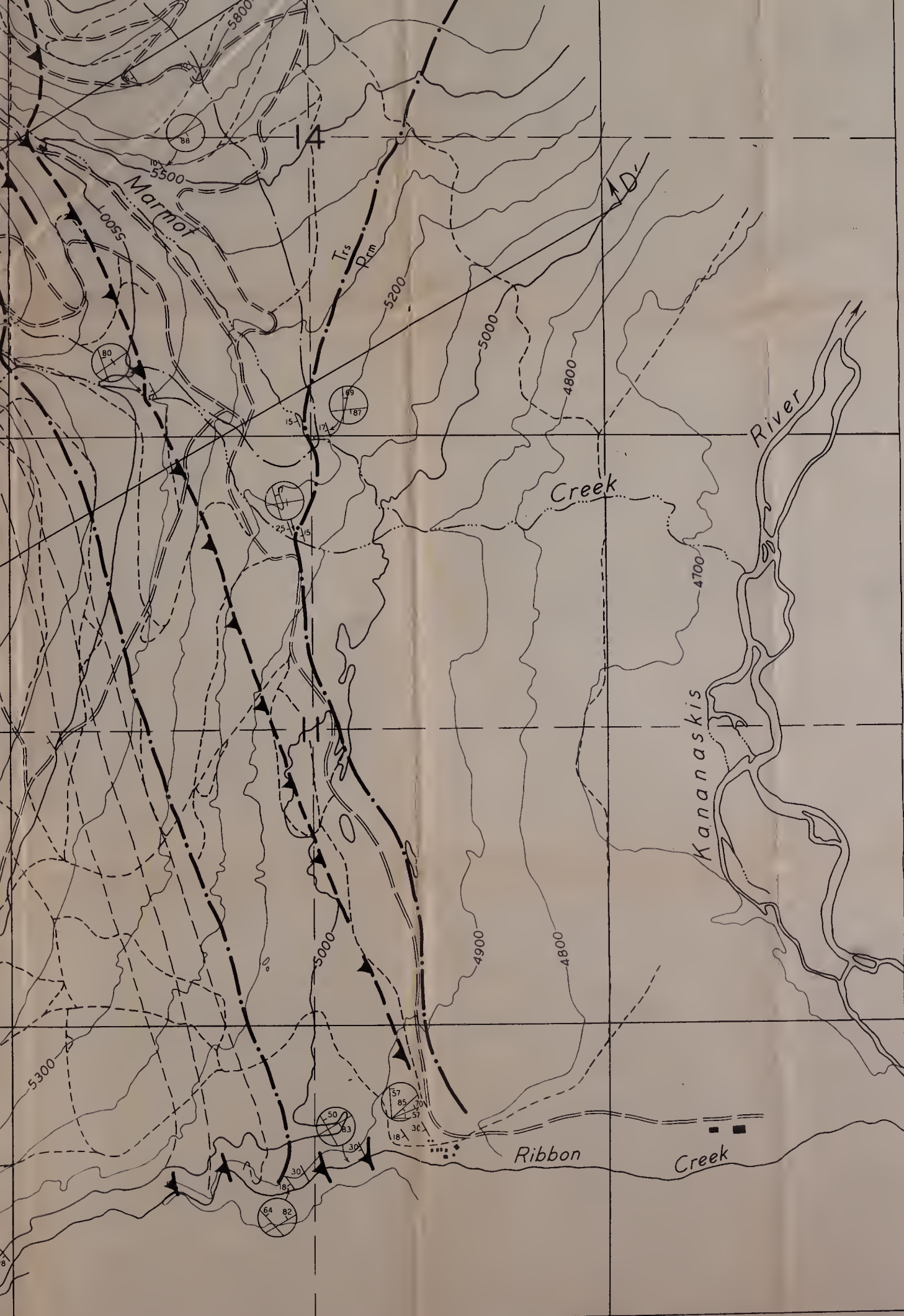




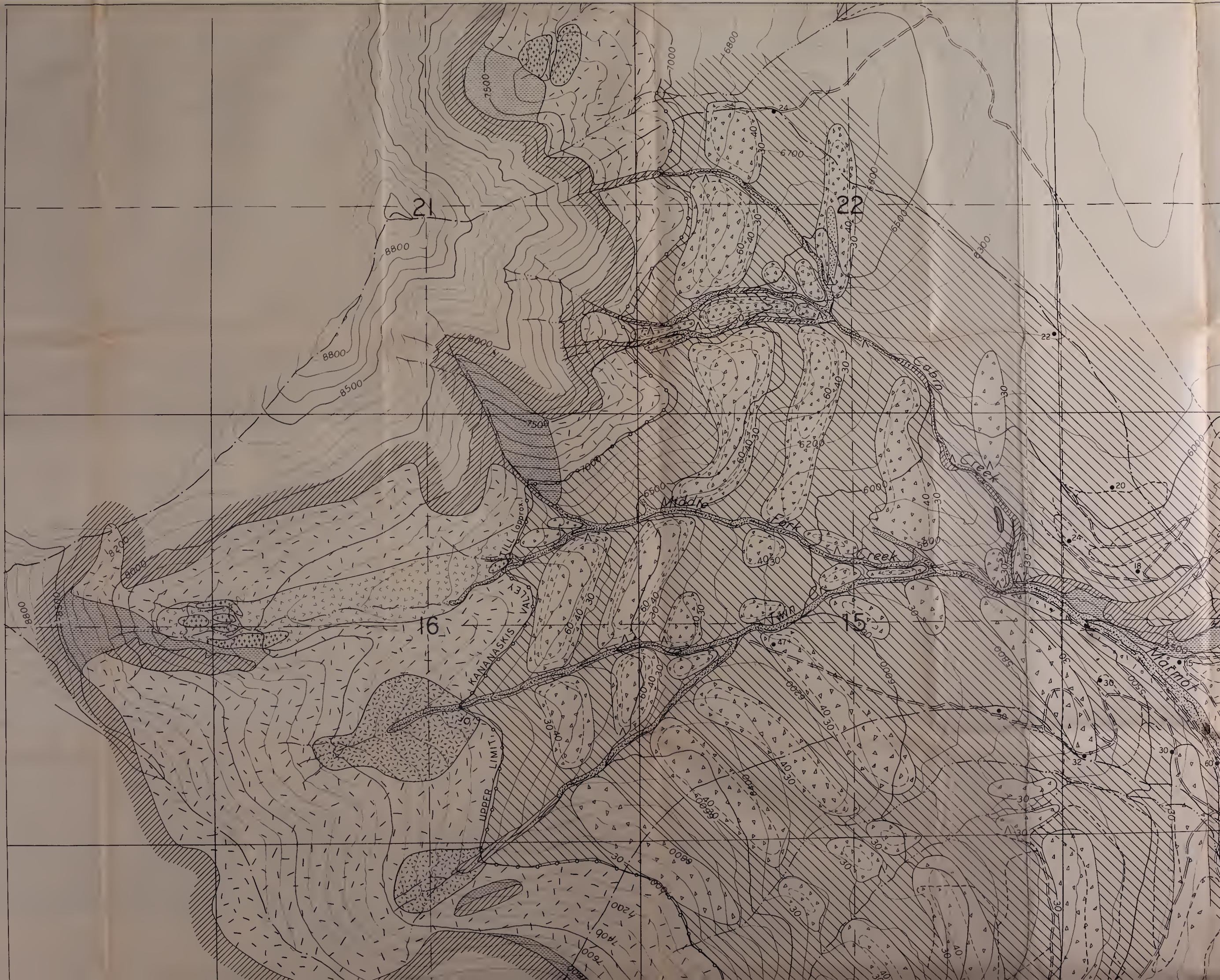
LEGEND

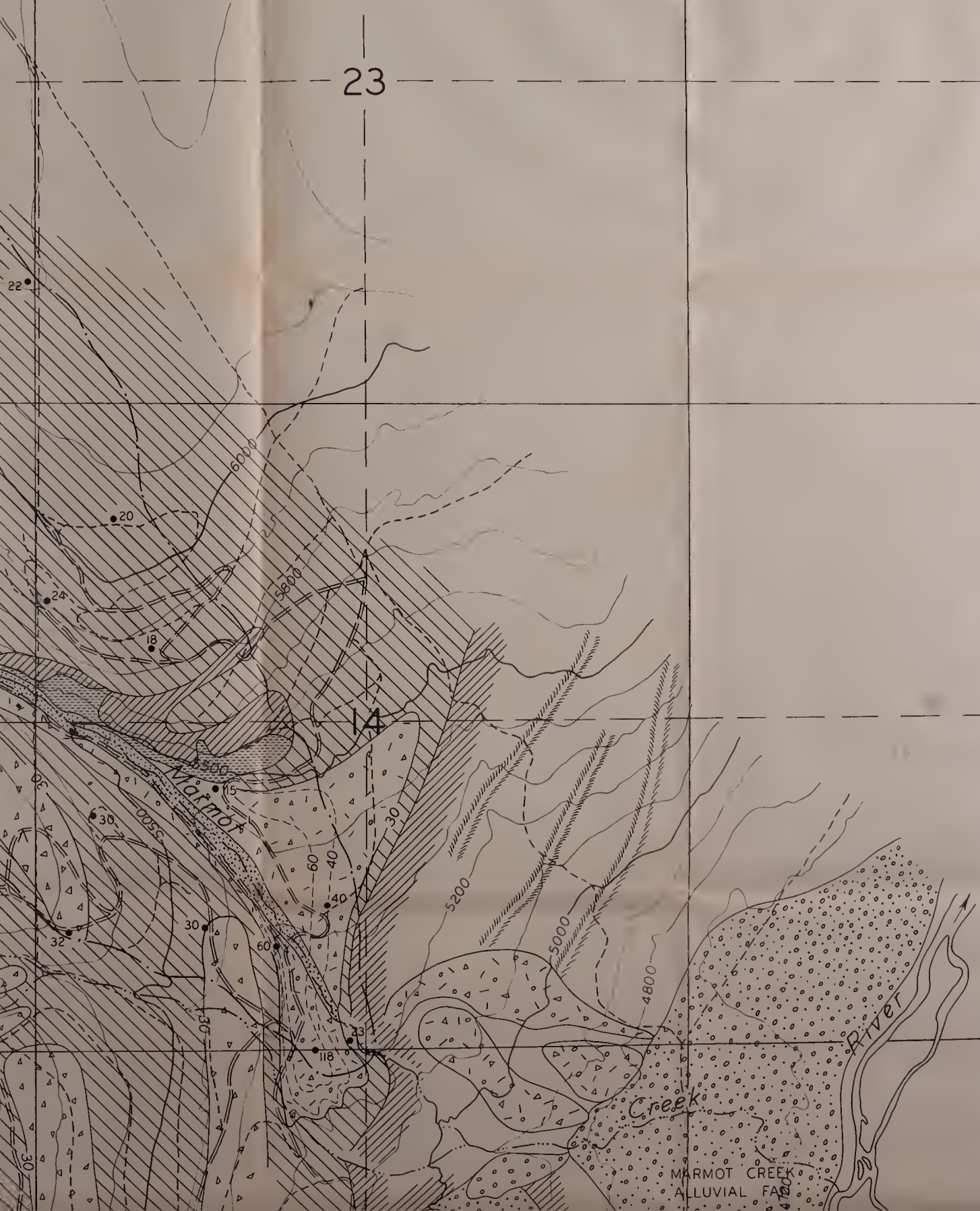
- Basin boundary (approx.)
- Formation boundary
- Member boundary
- Significant lithology changes
- Exposed thrust fault
- Inferred thrust fault
- Normal fault
- Overturned syncline with direction of plunge
- Bedding (inclined, vertical, overturned)
- Joint set; strike and dip of joint planes encircled
- Cross section line

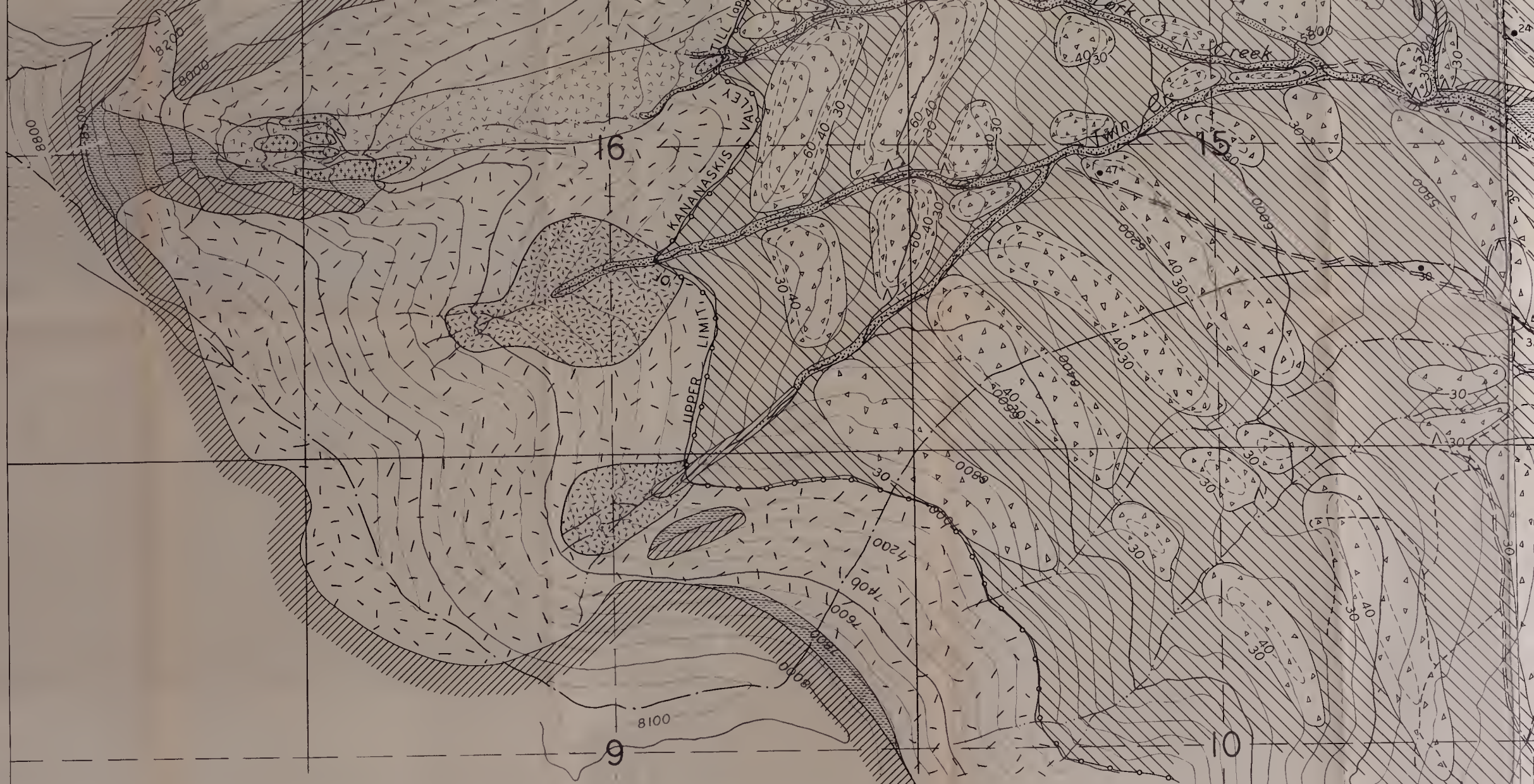




Map 4. Bedrock Geology of the Mamot Creek Basin







LEGEND

CENOZOIC

QUATERNARY

POSTGLACIAL

- Talus, mainly local bedrock (*low carbonate content*)
- Alluvial, gravel, sand and silt
- Lag deposits along stream channels (*fine materials removed*)

PLEISTOCENE AND POSTGLACIAL

- Local residual deposits and colluvium (*low carbonate content*)
- Thick local deposits in nivation hollows (*low carbonate content*)
- Kananaskis Valley till and colluvium (*carbonate content decreases south to north*)
- Thick deposits of moraine, outwash and colluvium

PLEISTOCENE

- Kananaskis Valley morainal ridges with large striated limestone erratics (*high carbonate content; contours show approx thickness in feet*)
- Thick hummocky cirque moraines
- Local lateral and end moraines (*low carbonate content*)
- Glacio-fluvial, ice-contact and (or) outwash
- Glacio-fluvial, hanging side valley gravel deposit, weakly calcite cemented

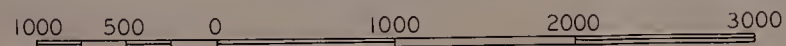
MESOZOIC

BEDROCK

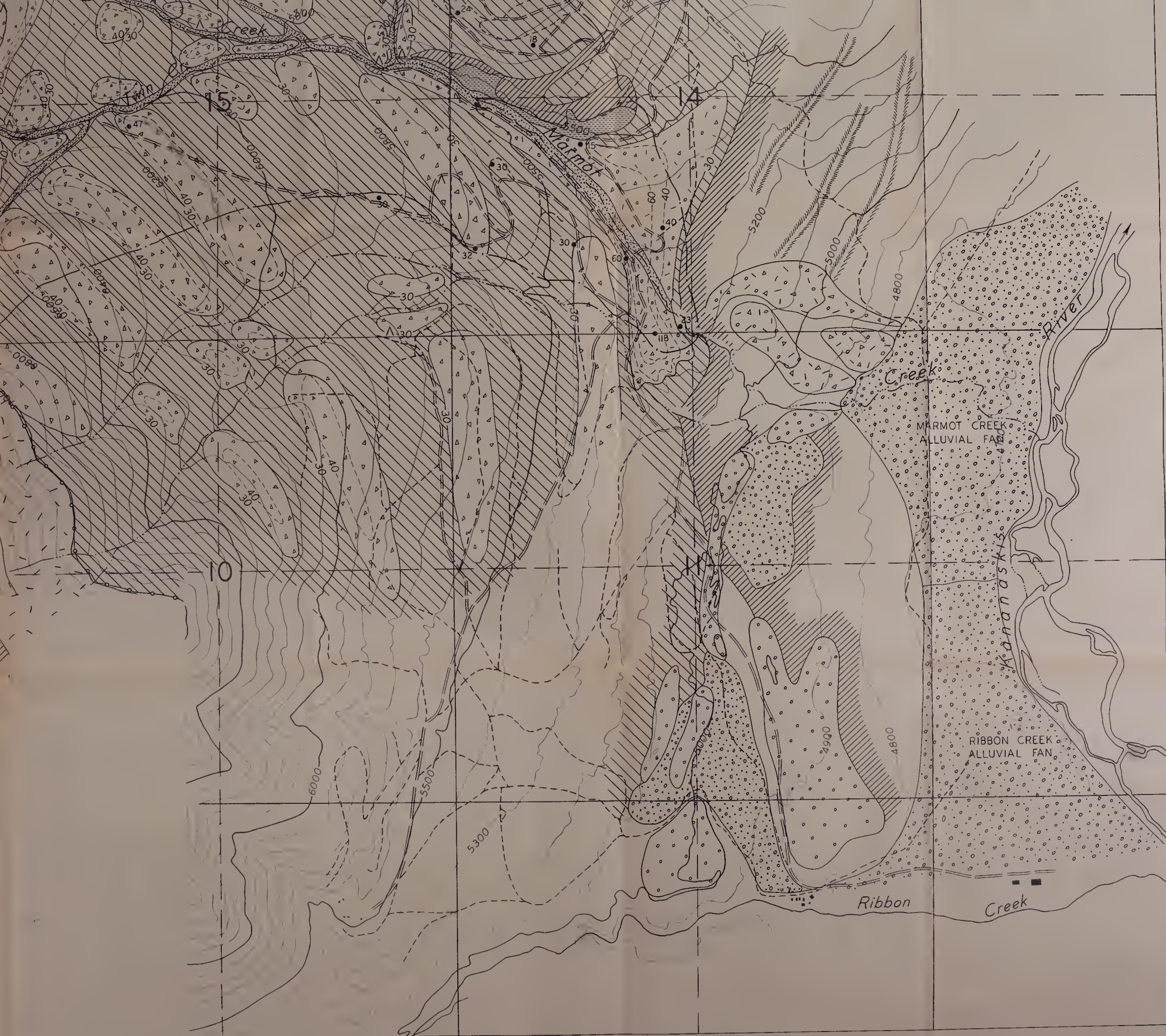
- Siltstone, shale, sandstone and conglomerate

- Borehole and depth to bedrock in feet ● 30
- Limestone erratic ▲
- Striated limestone erratic ▲
- Side glacial meltwater channel
- Basin boundary

SCALE IN FEET



Tp.23 R.9 W5 Meridian





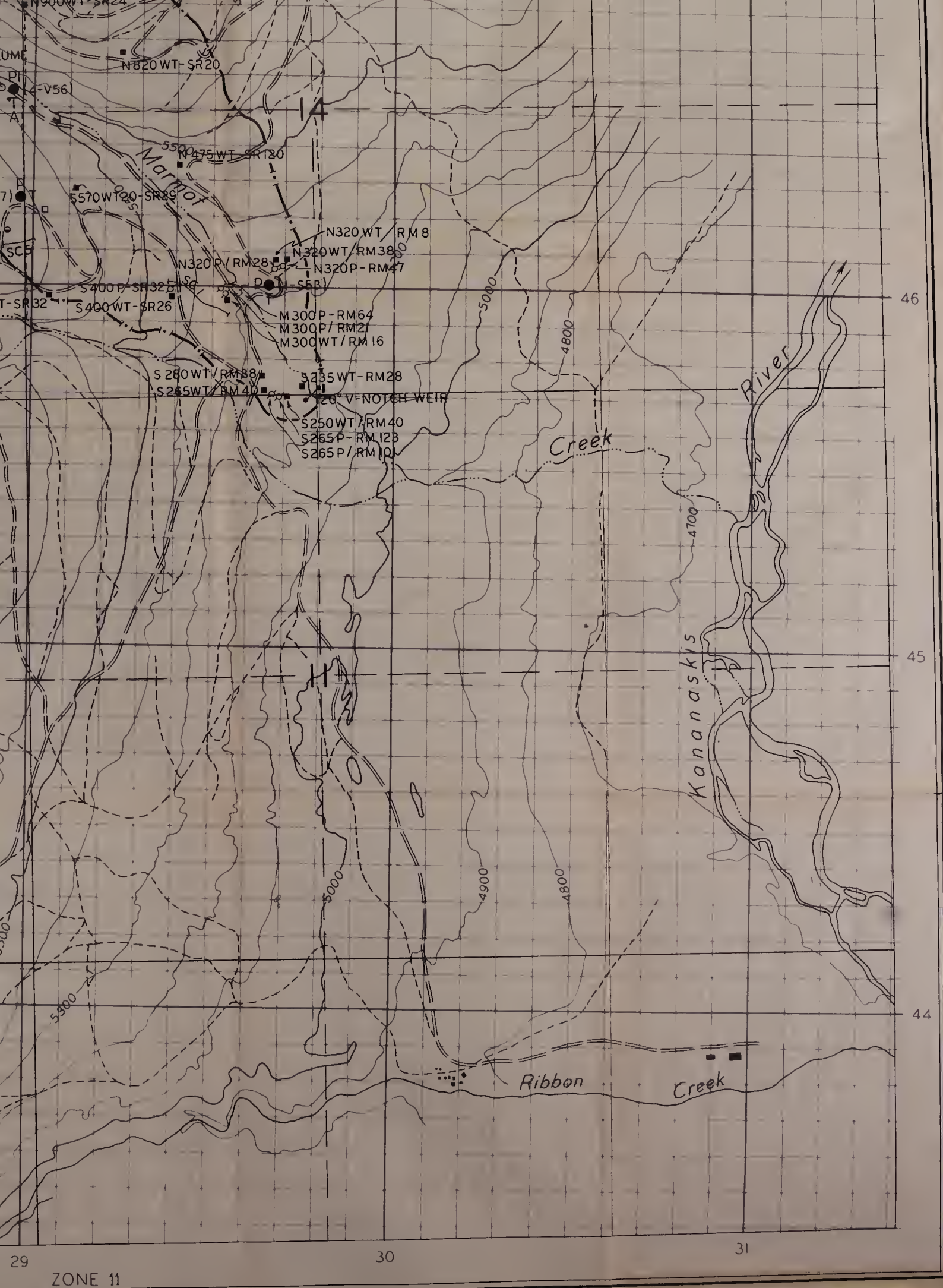


23

48

47

46



Map 6. Hydrologic Instrumentation of the Marmot Creek Basin

0 1620 1066 9820

B29865